THIN WALL FOUNDATION TESTING

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

[redacted]

THIN WALL FOUNDATION TESTING

March 1992

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

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EXECUTIVE SUMMARY

A recent project by the Department of Civil Engineering, University of Alberta studied the feasibility of building residential basement walls of unreinforced concrete thinner than the conventional 200 mm thick wall. The study determined 150 mm as the optimum reduced thickness for an unreinforced 2,400 mm high foundation wall and concluded that savings of $600 to the homeowner could be realized. Technical analysis was based on equivalent fluid pressures and indicated that the 150 mm foundation would be suitable for use with sand and gravel backfill material. For walls backfilled with other than clean sand and gravel, it was found that the theoretical maximum backfill heights for both 150 and 200 mm walls are substantially less than those presently specified by the Alberta Building Code. However, since the practice of backfilling with stable native soils (characterized by significantly higher equivalent fluid pressures) is common and house foundations have performed well under these conditions, it was concluded that either the accepted values for equivalent fluid pressures or the assumed triangular distribution of lateral soil pressures was in question, and the testing program described in this report was recommended.

The primary purpose of this project was to test, in field-constructed conditions, the performance of a 150 mm unreinforced foundation wall, under varying lateral loads as would be imposed by differing soil types. Additional objectives were to determine lateral load characteristics for various soil types typical to Alberta, to confirm the behavior of the foundation wall as a function of lateral load, and to compare measured and calculated lateral loads to the equivalent fluid pressure specified as a performance criteria in the Alberta Building code.

Project work took place in Strathcona County, east of Edmonton, Alberta, from October 1990 through to March 1992.

Lateral earth pressures resulting from two soil backfill types - sandy lean clay (clay-till) and sand were investigated. The clay-till soil was placed in three different states - overwinter, tamped and loose. The foundation walls were visually monitored and wall deflections were measured over the term of the project. No physical distress in the form of wall cracks or other deleterious effects on the 150 mm thick concrete walls were observed during the study.

Two design methods based on the concept of equivalent fluid density were evaluated with respect to the measured field conditions. The analysis of clay-till case studies indicated that the methods of Equivalent Fluid Density and Terzaghi and Peck's Design Charts are

generally conservative, that is, they tend to overestimate earth (soil) pressure distributions.

The analysis of loose sand demonstrated very good agreement between measured pressure distribution and the method of Equivalent Fluid Density. However for the loose sand the Terzaghi and Peck Design Charts method largely underestimated measure values.

Project work verified that different soil types exhibit different equivalent fluid densities, consistent with the literature. For longer term placement conditions, the observed pressure distributions support the hypothesis of a triangular soil pressure distribution, and can be described by traditional earth pressure theory.

The measured lateral wall deflections, under the loads applied by the backfill soils, were consistent with the deflection estimates using the methods of Finite element and Simple Beam Analysis, and confirm that the thin walls behave as elastic concrete beams.

Within the scope of the project objectives and the two soil types tested, the following comments and recommendations were developed:

- The use of 150 mm thick foundation walls for single family dwellings appears feasible in terms of construction, cost and performance under service conditions from the applied backfill soil loads and groundwater conditions encountered in this study. Surface compaction should be limited to 85% - 95% of optimum density.

- The Alberta Building Code allows for 150 mm thick foundation walls, and specifies that walls supporting well drained soil backfill may be designed for a pressure equivalent to that exerted by a fluid with a density of not less than 480 kg/m^3, and having a depth equal to that of the retained earth. The Code also provides in Table 9.15.4A, recommendations for acceptable backfill heights for various wall thicknesses. This table is based on an equivalent fluid density of 480 kg/m^3. Table 9.15.4A should not be used to obtain acceptable backfill height for any backfill soil other than clean free draining granular material. Further, the recommendations of Table 9.15.4A should be re-evaluated for other soil types having characteristically higher equivalent densities. The table of acceptable backfill heights should also address conditions where water pressures may act on the walls, in addition to the soil pressures. This condition could be encountered where the foundation drainage system or weeping tile becomes

blocked or ineffective during the life of the building.

- Methods of design such as the Equivalent Fluid Density Method and Terzaghi and Peck's Design Charts tend to be empirical in nature and often conservative as observed in this report. Use of earth pressure theory in design is a common practice and can be extended to small projects such as house foundation design.

1.0 INTRODUCTION

1.1 Purpose of the Project

In Alberta, house foundations are generally constructed as 200 mm thick concrete walls resting on strip footings which in turn rest on undisturbed soil below the frost line. Minimal reinforcement is employed, and generally consists of parallel horizontal bars at the top of the wall to minimize cracking at that location.

The primary purpose of this project was to test, in actual field-constructed conditions, the practical performance of a thinner foundation wall, specifically a 150 mm unreinforced concrete wall, under varying lateral loads as would be imposed by differing soil types. Additionally, project work was structured to respond to the following objectives:

1. to determine lateral load characteristics for various soil types typical to Alberta,
2. to confirm the behavior of the foundation wall as a function of lateral load, and
3. to compare measured and calculated lateral loads to the equivalent fluid pressure specified as a performance criteria in the Alberta Building Code.

The rationale for these objectives is explained in the Sections which follow.

Project work took place in Strathcona County, east of Edmonton, Alberta and was carried out from October 1990 through to March 1992.

1.2 Project Background

1.2.1 Alberta Building Code

Single family dwellings comprise one of several building types governed by Part 9 of the Alberta Building Code (ABC). Within that Part, Sections 9.4, Structural Requirements, and 9.15, Footings and Foundations, apply to the work of this project.

Article 9.4.4.6, at Sentences (1) and (2), states:

"(1) Walls supporting drained earth may be designed for pressure equivalent to that exerted by a fluid with a density of not less than 480 kg/m^3 and having a depth equal to that of the retained earth.

(2) Any surcharge shall be in addition to the equivalent fluid pressure specified in Sentence (1)."

Article 9.15.4.2 introduces Table 9.15.4.A, which specifies minimum foundation wall thicknesses for heights not exceeding 2.5 m in average stable soils. For reference purposes, Table 9.15.4.A is reprinted below.

It is interesting to note that the ABC, by virtue of Table 9.15.4.A, allows the use of 150 mm thick foundation walls for buildings governed by Part 9.

Table 9.15.4.A: Forming part of Article 9.15.4.1

THICKNESS OF FOUNDATION WALLS			
		MAXIMUM HEIGHT OF FINISH GRADE ABOVE BASEMENT FLOOR OR INSIDE GRADE	
TYPE OF FOUNDATION WALL	MINIMUM WALL THICKNESS (mm)	FOUNDATION WALL LATERALLY UNSUPPORTED AT THE TOP	FOUNDATION WALL LATERALLY SUPPORTED AT THE TOP
SOLID CONCRETE (15 MPa MIN STRENGTH)	150 200 250 300	0.80 1.20 1.40 1.50	1.50 2.15 2.30 2.30
SOLID CONCRETE (20 MPa MIN STRENGTH)	150 200 250 300	0.80 1.20 1.40 1.50	1.80 2.30 2.30 2.30
UNIT MASONRY	140 190 240 290	0.60 0.90 1.20 1.40	0.80 1.20 1.80 2.20
COLUMN 1	2	3	4

1.2.2 Previous Related Work

Research completed in 1990 at the University of Alberta Department of Civil Engineering with the support of the Innovative Housing Grants Program investigated the feasibility of building single family dwelling concrete foundation

investigated the feasibility of building single family dwelling concrete foundation walls thinner than the conventional 200 mm. No target thickness was predetermined, rather the research work was structured such that an optimum reduced thickness could be identified. A limiting criterion specified that the optimum wall should require no engineering design or certification. The optimum thickness, in terms of economic and technical viability, was determined to be 150 mm. As noted earlier in this Section, this thickness is presently allowable by code under some circumstances, but is not used in practice. The study determined that $600 could be saved from the cost of an average foundation if 150 mm foundation walls were to be employed.

The study involved the use of equivalent fluid pressures for determining lateral loads imposed on foundation walls by backfilled materials and acknowledged that this is an approximate design procedure. It was further assumed that lateral soil pressures against a foundation wall have a triangular distribution. Analysis indicated that a 150 mm thick foundation wall would be suitable for use with sand and gravel backfill material. For walls backfilled with soils other than clean sand and gravel, it was found that the theoretical maximum backfill heights for both 150 mm and 200 mm walls are substantially less than those presently allowed by the Alberta Building Code. Since the practice of backfilling with stable native soils (which are characterized by significantly higher equivalent fluid pressures) is common and house foundations have performed well under those conditions, the study therefore concluded that either the accepted values for equivalent fluid pressures or the assumed triangular distribution of lateral soil pressures are in question.

A full-scale testing program was therefore recommended, to provide measured data against which the design assumptions could be tested, and to demonstrate and evaluate the performance of a 150 mm thick foundation wall under actual field conditions.

1.2.3 Site of the Work

In July 1990, an agreement to construct a research facility, for the purpose of facilitating various studies relating to lot grading and drainage, was finalized. Participating sponsors for this project are Alberta Municipal Affairs, the City of

Edmonton, Strathcona County and the New Home Warranty Program of Alberta. One of the ongoing research objectives to be addressed at the facility involved the regular changing of backfill material such that the effects of various soil types on foundation drainage can be determined. These circumstances presented an unique opportunity for facilitation of further research respecting the loading and deformation of thin wall foundations.

In September 1990, the sponsors of the lot grading and drainage research facility endorsed this project and agreed that it could be undertaken at the site of the research facility without detriment to concurrent lot grading and drainage projects. The research facility, therefore, was designed with 150 mm foundation walls to accommodate testing and research into thin wall foundations, the subject of this project. The research facility, which in essence comprises a tract house, was built in October 1990 in Strathcona County.

1.3 General Methods

Project researchers provided design input for the structure, and closely monitored construction work. Specifically designed instrumentation allowed continuous collection of relevant data, including soil pressures and wall deflections. Subsequent analytic work included an assessment of the practicality and economics of the 150 mm foundation walls, and a detailed engineering analysis of the behavior of the walls and the lateral pressure characteristics of the soil types studied.

Throughout the project, the requirements and circumstances of the general lot grading and drainage took precedence over those of this project. It was initially envisioned that at least three and as many as five soil types would be available for analysis as backfill materials. However, within the time limitations of this project, circumstances permitted only a single change of material, such that only two distinct soil types (clay till and sand) were available for study. Project results, therefore, are somewhat tempered by this limited change in backfill soil types.

1.4 Report Structure

The ensuing Parts of this report discuss in detail the methods, observations, findings and conclusions of the study and are presented as follows:

- Part 2 describes project design features, construction of the 150 mm foundation walls, project instrumentation, and initial and final backfill operations.

- Part 3 describes the data collected relating to the two backfill operations.

- Part 4 contains laboratory analysis data for the soil types studied.

- Part 5 discusses the economics of the 150 mm wall by comparing actual construction costs to costs estimated in the previous study described in Subsection 1.2.2.

- Part 6 encompasses the engineering analysis.

- Part 7 presents the conclusions and recommendations of the study.

2.0 DESIGN, CONSTRUCTION AND INSTALLATION

2.1 Design of Test Panels and Load Cells

In order to select a method for measurement of backfill soil pressures, a review of commercially available pressure cell types or measuring devices was carried out. The review indicated that the available pressure cells would generally be unreliable for measurements in the low range of backfill soil pressures anticipated for this work. Previous experience with load cell technology at the University of Alberta had reported successful measurements of lateral earth pressures. Load cells were therefore specifically built for this project at University laboratories, and a system to measure the forces on a concrete test panel employing the cells was developed. The testing configuration incorporates a set of "dummy" plywood panels anchored to the foundation wall on each side of the "active" concrete test panel, as illustrated by Figure 1, Appendix A, in order to eliminate the effects of

bridging and pressure irregularities across the front of the test panel.

The concrete test panels were designed to act as hinged plates, such that soil pressures acting on the panels were transferred as loads to the foundation wall through the load cells which were anchored to the foundation wall and in contact with the active concrete test panels. The dummy panels provided assurance that bridging and resultant pressure irregularities would not affect or compromise the orthogonal (lateral) pressures acting on the faces of the active panels.

The load cells consist of four electrical strain gauges mounted on aluminum dowels using a temperature compensating Wheatstone bridge configuration. Each assembly was waterproofed using a heat shrink plastic sleeve. Site photographs of the wall-mounted load cells are contained in Appendix E.

The active concrete test panels and the wood dummy panels were fabricated on site and installed by the foundation contractor, Revelyn Construction Alberta Limited. Site photographs of the installed panels are located in Appendix E.

2.2 Construction of Thin Wall Foundation

Construction of the 150 mm thin wall foundation was awarded to Revelyn Construction Alberta Limited, 19 October 1990. The work was carried out during the period 25 October to 5 November 1990. Foundation construction was continually monitored by University of Alberta personnel. No construction difficulties were encountered with respect to the forming and placing of the concrete for the 150 mm thick foundation walls. Six concrete test cylinders were provided by the ready-mix supplier, Revelstoke Concrete Inc. for compressive strength testing. Concrete cylinders were tested at the University of Alberta Structures Laboratory, and yielded 6 and 27 day compressive strengths in the range of 20.6 to 23.7 Mpa. This concrete was ordered as 20 MPa concrete which is normally specified for local house foundations.

2.3 Installation of Panels and Load Cells

Field installation of the wall anchors for mounting of the load cells to the foundation walls was carried out on 5 November 1990. Installation of the load

cells and erection of test panels took place on 12 November 1990. The location of the load cells with respect to the active concrete panels is shown be Figure 2, Appendix A. Dummy cells were used to measure effects of temperature and humidity on transducers with the effects of load. The load cells readings were then adjusted for these effects. Deflection measuring dial gauges were installed on 16 November 1990. The gauges were mounted to concrete shear walls which had been provided inside the structure as a safety measure for the study, in the event of wall collapse. The shear wall detail and locations of dial gauges are illustrated on Figure 3, Appendix A.

A review of the dial gauge measurements throughout the winter found the system to be susceptible to time dependent dimensional changes within the shear wall as a result of concrete curing, and gauge reading irregularities due to moisture changes, frost and possible tampering. As a result, a system of extensometer measuring points were installed on 26 April 1991 on the interior of the foundation walls and floor. This provided a better system for measuring the wall deflections, with the dial gauges serving as backup.

Figure 4 illustrates the completed data measuring system.

All testing equipment was installed by University of Alberta personnel, in cooperation with the foundation contractor. The plywood dummy panels were damp-proofed with a bituminous coating. Gaps between the active concrete panels and the dummy panels were sealed with a bituthene self adhesive strip material. A cold weather mastic asphalt agent was also used to aid the adhesion of the bituthene to both the concrete and wood members. These seals were intended to prevent the ingress of soil but were not capable of preventing water penetration behind the panels.

2.4 Backfilling Operations

The foundation excavation was backfilled by Strathcona County personnel on 27 November 1990. Backfilling operations were carried out with a Caterpillar track-mounted loader. The native backfill material consisted essentially of clay and silt with some sand and gravel, classified as clay till soil by geotechnical analysis. The backfill material was predominantly frozen at the time of

placement. The upper surface of the backfill was compacted by the track action of the loader, and surface grading was carried out with the bucket. The combination of drainage piping, frozen backfill and the relatively large size of loader prohibited achieving a uniform degree of compaction.

Backfill variation related to for the drainage study was initiated 1 May 1991 by CH2M Hill Engineering Ltd. This initially consisted of tamping the upper region of the wintered clay till backfill, surface grading and placement of sod or other surface treatment related to the drainage characteristics defined in their study. Only two subsequent changes of the backfill soils were made during the drainage study. The tamped clay till backfill was excavated and replaced with loose clay till on 21 August 1991. The loose clay till backfill was in turn replaced by loose sand on 10 September 1991.

Backfill soil samples were collected at various times throughout the study for purposes of soil classification and engineering analysis. The methods of sample collection are discussed in Part 3 and the results of all laboratory testing are presented in Part 4.

3.0 DATA COLLECTION

3.1 Background

Over the course of the drainage study (May to October, 1991), only two backfill soil types (clay till and sand) were used, under the varying conditions mentioned above and described by various drainage-oriented terms of reference. The scope of the Thin Wall Foundation Testing Project was therefore limited to the following four case studies:

27 November 90	-	26 April 91:	Clay Till, Frozen
30 April 91	-	19 August 91:	Clay Till, Tamped
21 August 91	-	9 September 91:	Clay Till, Loose
10 September 91	-	27 September 91:	Sand, Loose

The original intent was to backfill around the foundation with up to 5 different soil types which would have been representative of the majority of soil types in

the province. Various limitations, however, restricted the study to only two soil types (clay till and sand).

Site visits and data collection were carried out by Department of Civil Engineering personnel in coordination with the drainage study requirements. Load cell readings for each site visit are contained on the Reduced Data Sheets located in Appendix B. Samples of the backfill material were collected throughout the fieldwork for purposes of laboratory classification and engineering analysis. The results of this testing are presented in Part 4.

Total lateral displacement of the foundation walls due to the placement of the backfill was measured using an extensometer tape gauge. Reference points for the measurements were obtained from wall bolts fixed at the top and mid-point of the wall and at midpoint of the floor span between the north and south walls. The measured wall deflections for the four case studies are presented in Section 6.3.

Inspection of the 150 mm thick foundation walls was carried out during backfilling operations and the walls were monitored throughout the case studies. No physical distress in the form of cracks or other deleterious effects were observed, throughout the study period of 15 months, from initial construction during October 1990 to last inspection during February 1992.

3.2 Field Work

Backfill soil samples were obtained by Department of Civil Engineering personnel at various times throughout the field study. The partially frozen clay till backfill was sampled on 27 November 1990. Two soil samples (sample numbers LS and SS) were recovered by pushing 75 mm O.D. thin wall Shelby tubes into the upper 0.6 m of backfill material with the aid of the excavator's bucket. One bulk surface sample (sample number BS) was also obtained. Samples of the tamped clay till backfill were obtained on 27 June 1991. The soils were sampled at 0.15 m test intervals to a depth of 1.1 m using a hand operated soil auger. Seven samples of the tamped clay till were recovered by hand pushing 38 mm O.D. thin wall Shelby tubes. A representative bulk sample of the sand backfill was obtained on 24 February 1992.

All soil samples recovered were stored in moisture proof containers and returned to, and stored in, the Department of Civil Engineering moisture room until laboratory classification and testing were complete.

4.0 SITE INVESTIGATION AND LABORATORY ANALYSIS

4.1 Site Geotechnical Report

As a requirement of the Lot Grading and Drainage Project, EBA Engineering Consultants Ltd. were retained by CH2M Hill Engineering Ltd., to install standpipe piezometers and carry out laboratory testing on recovered soils from the sampled borehole locations. EBA's report characterized the soil stratigraphy as extremely variable across the site, comprising essentially fill material to a depth of at least 3 m, the maximum depth of boring. Fill materials encountered in the boreholes are described as topsoil, clay, clay till and reworked clay shale, with traces of gravel, sand, organics and coal. The fill appears to have been derived from excavated materials on site.

Soils were sampled in four primary borehole locations with Shelby tubes at approximately 0.5 m test intervals to a maximum depth of 3.0 m. Pocket penetrometer readings on recovered Shelby tube samples indicated undrained shear strengths in the range of 100 to 400 kPa, which led to their description as stiff to very stiff in terms of soil consistency. Laboratory soil tests consisted of moisture content, density and permeability. The average moisture content and wet density of the clay samples tested were 16.2% and 2018 kg/m^3 respectively. Constant head laboratory permeability tests performed on two clay samples from two additional shallow (1.5 m) boreholes yielded values of 1.1 x 10^{-9} m/s and 6.4 x 10^{-11} m/s, typical of stiff clay soils.

4.2 Laboratory Analysis of Foundation Backfill Materials

Clay Till

Laboratory testing on the clay till consisted of grain size distribution (sieve and hydrometer), Atterberg limits, moisture content and density. The results of these tests are summarized in the table below and on the Gradation Curves presented in Appendix C.

Table 1: Summary of Clay Till Laboratory Test Results

Backfill Type	Sample No.	Date (D/M/Y)	Grain Size Distribution				Moisture Content	Atterberg Limits			Wet Density
			Gravel %	Sand %	Silt %	Clay %	W %	WL %	WP %	PI %	D kg/m^3
Clay Till	LS	27/11/90	0.7	33.2	35.0	31.1	17.2	50.3	28.7	21.6	NP
Clay Till	SS	27/11/90	3.7	34.5	33.5	28.3	20.8	49.3	30.7	18.6	NP
Clay Till	BS	27/11/90	1.8	30.8	34.9	32.5	20.0	43.2	19.9	23.3	NP
Clay Till	BS	18/06/91	NP	NP	NP	NP	26.4	NP	NP	NP	1900

Notes:
1. NP indicates a particular test was not performed.
2. Values indicated for 18/06/91 represent the average of seven test samples recovered from 0.0 m to 1.1 m depth.
3. WL=liquid limit, WP=plastic limit, PI=plasticity index=WL-WP; all expressed as moisture content as percent of dry weight of sample.

Average grain size characteristics resulting from the three complete sieve and hydrometer analyses performed on the clay till backfill were 2.1% gravel, 32.8% sand, 34.5% silt and 30.6% clay. In accordance with ASTM Standards, the clay till backfill may be described as Sandy Lean Clay, and is classified as CL. In terms of average group constituents, the fill may be summarized as brown, sandy silt and clay of medium plasticity with occasional gravel; having traces of organics, rootlets and coal.

Sand

A moderately clean granular backfill was placed on 10 September 1991. The backfill consisted of brown sand having occasional gravel and traces of silt. One sieve analysis on the sand yielded the following in terms of grain size percentages; 8.2% gravel, 85.3% sand and 6.5% silt. Field inspection of the backfill indicated that the sand was in a very loose to loose condition in terms of its relative density.

5.0 COST ESTIMATE COMPARISON

5.1 Cost of Concrete Foundation

A comparative cost study (referenced in Subsection 1.2.2) for house foundations

had been completed in October 1989. The study included a range of wall thicknesses and concrete strengths for two house sizes in eight locations across the province of Alberta. The study projected savings in the order of $600 ($13.89/metre) for a 'standard' 9.6 m x 12 m x 2.44 m high basement in Edmonton, if built 150 mm thick instead of the conventional 200 mm thickness.

The award and subsequent construction of this research facility provided cost data for comparison. The contractor estimated, based on his bid, that the savings in the 150 mm vs 200 mm foundation walls would be $591. The saving is due entirely to the saving in concrete, i.e. 4.88 m^3 @ $121/$m^3$ or $14.78/metre of wall perimeter.

This saving compares favourably with the predicted savings and can be increased slightly for a project with multiple units. For larger houses, the savings could be greater.

6.0 ENGINEERING ANALYSIS AND DISCUSSION

This Section of the report discusses various methods for determining lateral loads against a foundation wall and compares theoretical loads to those measured within the scope of this project. Further, it discusses soil pressures, the effects of compaction, and wall deflection from both practical and analytical perspectives. For the benefit of the reader, whose level of interest may depend on degree of involvement, an attempt has been made to distinguish between project-specific and detailed analytic texts. Background and project-specific discussion are presented in normal type, while detailed analytic treatment and discussion on design methods are in italics.

6.1 General

The pressure exerted by an earth backfill against a retaining structure can be calculated with reasonable accuracy on the basis of theory, but only for conditions rarely encountered in practice (Peck, Hanson and Thornburn, 1974). Theoretical analyses are usually simplified by assuming ideal homogeneous and isotropic materials having constant material properties and consistent behavior. The designer must have advance notice of what materials are to be used for backfill, their

condition of placement and their physical properties. Also, once the materials are placed, the designer must be assured that their physical properties remain constant. These conditions are rarely satisfied on many smaller projects, especially for the foundation of a house.

Ordinarily, the designer learns in advance of construction little more than the general type of backfill which is to be used. Stringent design specifications, quality assurance programs and continuous monitoring of construction activity to verify the design assumptions, cannot generally be satisfied economically except for the larger and more expensive projects. Hence, theoretical earth pressure calculations can rarely be justified during the design of a residential foundation, because the physical characteristics of the backfill are not usually known prior to its placement in the field. Therefore, traditional design of residential foundations has been carried out by the use of design charts and methods having a part theoretical and part empirical basis. The applications of these methods have been incorporated into building code requirements, such that detailed engineering design is typically not required, provided the recommended code requirements are followed.

These design methods are generally conservative to ensure both safety and economy with respect to accepted construction practice and foundation design. Knowledge of earth pressure theory, such as Coulomb's (1776) or Rankine's (1857) Theory of Earth Pressure, permits recognition of the more important variables which influence earth pressure, improve engineering judgement and better define the current design rationale.

6.2 Method of Analysis

For traditional design of low retaining walls (height less than 6 m), and where the project cost is relatively small, elaborate soil testing and detailed earth pressure computations are typically not justified. In particular, for the design of house foundation walls, the use of two principal design methods have been promoted; the Equivalent Fluid Method and Terzaghi and Pecks Design Charts (foundation requirements in Part 9 of the Alberta Building Code are derived from the Equivalent Fluid Method). These methods are recognized by such standards as the Canadian Foundation Engineering Manual (1985) and Engineering Design in Wood, CSA (1984). Both methods are based on the concept of an equivalent

fluid pressure. The concept requires that the backfill soil be treated as a fluid of an equivalent soil density based on a soil type classification system. Implicit in this assumption, is that the pressure exerted by a particular backfill takes the form of a triangular distribution increasing with depth,as occurs with a fluid. This condition is also known as a hydrostatic pressure distribution.

A triangular soil pressure distribution or hydrostatic distribution has been recognized at least as early as Rankine's introduction of earth pressure theory in 1856. The concept is discussed in most soil mechanics texts, including Terzaghi and Peck (1967) and Lambe and Whitman (1969). A variety of other pressure distributions are also recognized throughout the literature, dependent on soil type, in situ density, type of retaining structure, height or depth of structure, whether or not the structure or wall is subject to displacement, and construction sequence to name a few.

In order to analyze the data measured by the load cells on the test panels, two assumptions regarding the pressure distribution were made - first, that the pressure distribution was uniform (constant regardless of depth), and second, that the pressure distribution was triangular. Reduced field data was then tested against these assumptions, to determine which, if either, was correct. Calculated results are recorded on the Reduced Data Sheets presented in Appendix B.

For a uniform pressure distribution, the upper and lower panel lateral loads would be expected to be equal. Calculations showed that this was not the case (for non-compacted material).

Further analysis of the field data confirmed that a triangular pressure distribution typically developed with time after placement of the backfill, corresponding to zero pressure at the top of the backfill, and increasing at constant slope to a maximum at the base of the wall or measuring panel. Plots of these findings are presented in Figures 5 to 9, Appendix D.

From project parameters and material characteristic data, design wall loads were computed using the Equivalent Fluid Method and the Terzaghi and Peck Design Charts. These design values were then compared to the actual wall loads which were derived from the observed triangular pressure distribution data for the

various backfill case studies.

For comparison and discussion of these methods, calculations were also carried out using the Rankine Method for theoretical earth pressure calculation. The formulas for determining the resultant horizontal wall loads, P(N/m), for each method are summarized below.

DESIGN METHOD	*FORMULA*
Triangular Pressure Distribution	$1/2\ (\sigma)H$
Equivalent Fluid Density	$1/2\ (\rho_e g)\ H^2$
Terzaghi and Peck's Design Chart	$1/2\ (K_H)\ H^2$
Rankine	$1/2\ K\ (\gamma)\ H^2$

In the above formulae, σ *is the calculated horizontal stress at the base of the earth pressure triangle, H is the height of backfill,* ρ_e *is the equivalent fluid density, g is the acceleration due to gravity and* K_H *is the horizontal pressure coefficient* (kg/m^3) *for a particular soil type specific to Terzaghi and Peck's design charts. For the Rankine Method, K represents the lateral earth pressure coefficient for the active* (K_a)*, at rest* (K_o) *or passive* (K_p) *pressure conditions, and* γ *is the soil unit weight* (kN/m^3).

6.3 Soil Pressures

Two principal soil types were identified during the course of the lot grading/drainage study and were referred to as clay till and sand. As previously noted, the clay till was classified as sandy lean clay, which occurs as a fill material at the field test site. The sand was imported for use as a relatively clean granular backfill material. Although the actual field study for the lot grading/drainage project took place in 1991, backfilling of the test facility, which was constructed in the fall of 1990, presented the opportunity to record soil behavior over the winter for the thin wall foundation study. The results of three case studies were analyzed for the clay till backfill, and one case study for the

sand backfill. The clay till studies include frozen, tamped and loose conditions. Only loose conditions could be investigated for the sand backfill.

The results of the analyzed pressure distributions showed that the triangular soil pressure distribution presented a very good fit to the field data, particularly in view of the longer term placement conditions. However, the short term effects of compaction and placement obscured the triangular distribution at the top of the test panels, and increased the distribution on the lower panels by an observed maximum of 25 percent (see also Section 6.4). Thus a limited zone of influence or pressure bulb resulted from the compaction equipment used at the ground surface adjacent to the foundation wall.

To compare the recorded field measurements with the suggested design methods based on equivalent fluid pressures, the horizontal wall loads resulting from the Equivalent Fluid Density and Terzaghi and Peck Design Chart methods were calculated according to the formulas noted in Section 6.1. The results are summarized in Table 2.

Table 2: Resultant Horizontal Load at Base of Wall

Soil Type	*Backfill Height m*	*Method of Calculation*		*Actual Load Cell Data kN/m*
		Equivalent Fluid Density kN/m†	*Terzaghi and Peck Design Chart kN/m*	
Clay Till (Frozen)	*1.48*	*17.19 (1600) 7.74 (720)*	*6.57 (K_H=6)*	*4.23*
Clay Till (Tamped)	*1.75*	*24.03 (1600) 10.81 (720)*	*9.19 (K_H=6) 7.66 (K_H=5)*	*5.61**
Clay Till (Loose)	*1.50*	*17.66 (1600) 7.95 (720)*	*6.75 (K_H=6) 5.62 (K_H=5)*	*7.02*
Sand (Loose)	*1.72*	*6.97 (480)*	*2.66 (K_H=1.8)*	*6.73*

Notes:

1. *Actual Load Cell Data is based on assumed triangular pressure distribution, validated by field data.*
2. *Equivalent fluid density: ( ) value indicates soil fluid density (kg/m^3) used for calculation of horizontal wall load. The value of the Equivalent Fluid Density is based on requirements of CFEM (1985). The two values for the till result from the soil classification assigned to this soil by the CFEM 1985.*
3. *Terzaghi and Peck Design Chart: ( ) value indicates selected pressure coefficient based on soil type.*
4. ** value represents largest load observed during recording period.*

5. † *Two values shown depending on how soil is classified. These are actual measurements. Fig. 9 shows that load in lower panel actually dropped below load in the upper panel. Compaction of soil locked load (stresses) into panels. This shows up as different actual loads per metre of wall perimeter.*
6. *1 KN/m (kilonewton per metre) is approximately equal to 68.5 pounds per foot.*

To facilitate comparison of the loads calculated in Table 2 with traditional soil mechanics theory calculations such as Rankine's earth pressure theory, values for the lateral earth pressure coefficient K, were also computed. The lateral earth pressure coefficient is the ratio of the horizontal to vertical stress at a given point in the soil mass at or below the ground surface. The earth pressure coefficients for the four case studies are presented in Table 3.

Table 3: Earth Pressure Coefficients (K)

Soil Type	Backfill Height m	Unit Weight kN/m^3	Horizontal Pressure kPa	Vertical Pressure kPa	Earth Pressure Coefficient (K)
Clay Till (Winter)	1.48	18.6	5.71	27.6	0.21
Clay Till (Tamped)	1.75	18.6	5.61	29.8	0.19
Clay Till (Loose)	1.50	18.6	9.36	27.9	0.34
Sand (Loose)	1.72	17.5	7.82	30.1	0.26

The above analysis was performed using effective stress. Piezometer data from the drainage study indicated a water table cone of depression leading to the weeping tile drain at the base of the foundation wall. Hence, zero water pressure acted on the walls for the cases studied. For this condition, analysis in terms of effective stress also equals that of total stress. Saturated soil unit weights were used in the calculations.

As previously noted, use of the equivalent fluid method or design charts is generally preferred for design of low foundation walls and retaining structures. For walls higher than 6 m, the use of earth pressure theory involving either active, at rest or passive pressure conditions is generally preferred. However, these high walls or systems of retaining structures deal more typically with retaining in situ soils, where construction sequence and wall flexibility play very important roles. A typical house foundation or wall is generally less than 2.5 m

in height and the magnitude of horizontal wall movement relative to its height is so small, that it can be reasonably and accurately described as a rigid and unyielding structure.

Therefore, both earth pressure theory and design practice recommend that this type of wall be designed for the 'at rest', or K_0 condition. Again, the hydrostatic or triangular pressure distribution applies.

Some typical design values for the coefficient of earth pressure at rest for various backfill conditions are presented in Table 4 below (Hunt, 1986).

Table 4: Coefficients of Earth Pressure at Rest K_0

SOIL TYPE	K_0
Normally consolidated clay	$(1 - \sin \phi')$
Compacted clay, hand-tamped	1.0 - 2.0
Compacted clay, machine-tamped (entire backfill)	2.0-6.0
Clay, overconsolidated	1.0 - 4.0
Sand, loosely dumped	0.5
Sand, compacted	1.0 - 1.5

In Table 4, ϕ' is the effective angle of internal friction, $0° \leq \phi' \leq 90°$.

By comparing the recommended design K_0 values shown in Table 4 with the computed K values for the case studies given in Table 3, it can be seen that the earth pressure at rest approach to design is conservative. In terms of the ratio of typical recommended design K_0 values to the computed field K values, the earth pressure at rest approach method to design would be about 1.9 (0.5/0.26) times the measured value for loose sand, and about 2.9 (1.0/0.34) to 5.9 (2.0/0.34) times the measured value for the loose clay till, based on the range of recommendations for normally consolidated and hand-tamped clay given in Table 4.

Clay Till

Review of the resultant horizontal wall loads in Table 2, generally shows that the two suggested design methods are conservative by comparison to the actual measured loads, with the exception of slightly low design values for loose clay till based on Terzaghi and Peck's design chart for clayey materials.

Sand

Review of the resultant horizontal wall loads in Table 2, shows close agreement between the actual data and that computed using the Equivalent Fluid Density Method based on an equivalent fluid soil density of 480 kg/m^3. The corresponding calculation based on Terzaghi and Peck's design chart is about 2.5 times lower than the measured value. A further check using the Rankine Method confirms that the Terzaghi and Peck design chart for sand appears much too low.

6.4 Effect of Compaction

The effect of compaction on the upper surface of the clay till was observed during the period 30 April to 19 August 1991. Initial compaction was carried out on the upper surface of the backfill using a backhoe tamper. Subsequent activities pertaining to the lot grading/drainage study included the addition or removal of up to 0.3 m of fill for grading requirements, flooding of the backfill, as well as changing of the surface cover (grass, bare soil or impermeable liner). The short term effects of the numerous changes performed during this period are difficult to quantify. Plots of the changing force distribution on the active test panels during this period are presented in Figure 10, Appendix D.

The plots demonstrate that the force on the lower active panels increased by a maximum of about 25 percent, while the upper active panels showed considerable increases in force of up to about 800 percent. By superimposing this increase on the original triangular distribution, a uniform or rectangular shaped pressure distribution results. Where the field measurements supported a triangular distribution, equivalent fluid density calculations using a soil density of 720 kg/m^3 produced results that would adequately account for the effects of

superficial compaction (see Table 2). In fact, for the longer term winter and tamped conditions, doubling the measured wall loads to account for a uniform distribution (compaction effect), showed the calculated wall loads based on 720 kg/m^3, to be within 10% (low side) of the measured value.

For the loose clay till however, to account for a uniform distribution (compaction effect), an equivalent fluid soil density of 1600 kg/m^3 appears more appropriate. Therefore, use of a particular equivalent fluid soil density should not only be based on soil classification, as is presently the case, but should also include consideration of its relative density.

The overall effect of surface compaction of the backfill is to essentially increase the force on the upper part of the wall by the locking in stresses due to compaction. The lower part of the wall experienced a decrease in load due to bridging effect of the upper compacted soils. This is illustrated by observing the data in Appendix B for the dates of August 7 through 19, 1991. This bridging effect will deteriorate with time but was not observed during this study because of excavation and replacement of the compacted soil.

In light of this discussion, the recommended design values of Table 4 can again be compared with the calculated values of K given in Table 3. The recommended design K values for loose sand appear reasonable (about double the measured values but reasonable for design.). The recommended design K values for clay soils appear to be quite conservative and reflect the high degree of uncertainty associated with these materials. Cohesive soils are not preferred backfill materials due to their potential frost susceptibility, potential swelling characteristics, very low permeability and potential related increase or build up of pore water pressure behind the wall, all of which serve to increase the loading or pressure on the wall. However, with respect to typical house foundation walls and the necessity or desire to use available or site excavated cohesive soils, provided good construction practice is maintained, an upper boundary K value of 1.0 appears reasonable based on the three case studies for the clay till.

As observed in Table 2, the greatest load on the wall was measured when the loose clay was used as a backfill. If we compute the resultant wall load based on a uniform pressure distribution to account for compaction effects, and

back-calculate the required K value to achieve the same actual measured loads based on an assumed triangular distribution, we find that K increases from 0.34 to 0.67. If we use a factor of safety of 1.5, the recommended design K becomes 1.0 as suggested from the project case studies.

Criteria for good construction practice are imperative. For instance, the use of over-sized compaction equipment around the top of the foundation wall could easily lock in very high horizontal stresses around these unyielding walls or potentially crack the foundation wall. A suggested field guideline to maintain compaction in the 85 to 95 percent range of optimum Standard Proctor dry density would eliminate any requirement for heavy compaction equipment.

6.5 Wall Deflections

Predicted Wall Deflections

Deflection estimates of the 150 mm thick foundation walls under the influence of the backfill soil were carried out using two methods. These consisted of Simple Beam Analysis using elastic theory, and Finite Element Analysis. Both methods consider the top and bottom of the wall to be rigid unyielding supports. The Finite Element Method also considered the case for a concrete wall with a rigid support at the bottom and a flexible, yielding support, which was provided by the wooden flooring system at the top.

The results of the Simple Beam Analysis yielded maximum wall deflections of about 0.47 mm under the action of soil backfilled to a wall height of 2.4 m, and considering the soil to have an equivalent fluid density of 480 kg/m^3. The corresponding deflections calculated using the Finite Element Method are 0.37 mm for an equivalent fluid density of 480 kg/m^3 and 0.62 mm for an equivalent fluid density of 720 kg/m^3.

The Finite Element Method, considering a flexible support at the top of the wall and rigid support at the bottom, yielded deflections of 0.39 mm for soil having an equivalent fluid density of 480 kg/m^3 and 0.65 mm for soil having an equivalent fluid density of 720 kg/m^3.

Measured Wall Deflections

Measured wall deflections corresponding to the four case studies were as follows:

CASE STUDY	BACKFILL HEIGHT (m)	LATERAL DEFLECTION TOP of WALL (mm)
Clay Till, Winter	1.48	1.3
Clay Till, Tamped	1.75	1.8
Clay Till, Loose	1.50	1.1
Sand, Loose	1.72	0.8

Lateral deflection measurements included both deflection and rotation components. Based on the Simple Beam Analysis, the predicted maximum deflection component is about 0.5 mm for sand (480 kg/m^3) and about 0.8 mm for clay (720 kg/m^3). The remaining measured deflection appears attributable to wall rotation.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Thin Wall Foundation Performance

The use of 150 mm thick foundation walls for single family houses appears suitable in terms of construction practicality (currently accepted construction practices for conventional 200 mm walls continue to apply), and the observed satisfactory wall performance under service conditions from applied backfill soil loads and groundwater conditions encountered in this study.

Cost savings in the order of $14/metre of wall perimeter can be achieved through the use of 150 mm foundation walls instead of 200 mm walls.

7.2 Lateral Load Characteristics and Design

The findings indicate that for longer term placement conditions, the resulting pressure distribution supports the hypothesis of a triangular soil pressure distribution, and can be described by traditional earth pressure theory.

If the Equivalent Fluid density method is used, appropriate selection of fluid densities according to the Canadian Foundation Engineering Manual is required. The coefficients of earth pressure computed from the case study indicate values which are more typical of active, i.e. K_a conditions, in terms of Rankine theory. As current practice of design of low walls using earth pressure theory is based on the earth pressure at rest, i.e., K_o values, it is concluded that the Rankine Method is also conservative or over-estimates the field measurement which corresponds to a triangular distribution.

Two design methods based on the concept of equivalent fluid density were evaluated with respect to the measured field conditions. The analysis of clay till case studies shows that the methods of Equivalent Fluid Density and Terzaghi and Peck's Design Charts are generally conservative or over-estimate the measured earth (soil) pressure distributions. The analysis of loose sand shows very good agreement with the measured distribution and the method of Equivalent Fluid Density. However, the method using the Terzaghi and Peck's Design Charts largely under-estimates the measured values.

Use of the Equivalent Fluid Density Method (as referenced in this report) will generally result in conservative design practice provided the correct equivalent fluid density for the particular backfill is used. The method assumes drained soil conditions. Any water pressures which may act against the wall must be added to the calculated soil pressures for design.

Methods of design such as the Equivalent Fluid Density Method and Design Charts tend to be empirical in nature and often conservative as observed in this report. The following table summarizes the accuracy of the design methods.

	SL CLAY	SAND
Equiv. Fluid Density	conservative	close agreement
Terzaghi & Peck	conservative	under-estimates
Rankine*	conservative	conservative

* Long term stress redistribution effects have not been observed or measured.

The pressure distribution resulting from compaction was observed to change from a triangular to a rectangular-shaped pressure distribution. It is imperative that oversize compaction equipment should be kept away from the backfill area. Compaction in the 85 to 95 percent range of optimum Standard Proctor dry density would eliminate the need for heavy compaction equipment. A built up fill sloping away from the foundation would compensate for soil settlement and still provide drainage away from the foundation.

7.3 Wall Deflections

The measured lateral wall deflections, under the loads applied by the backfill soils, were consistent with the deflection estimates using the methods of Finite Element and Simple Beam Analyses, and confirm that the thin walls behave as elastic concrete beams.

7.4 Alberta Building Code Criteria

Table 9.15.4A of the Alberta Building Code is based on an equivalent fluid density of 480 kg/m^3,. which is acceptable for sand or granular materials, and is for drained conditions, where hydrostatic forces or water pressures are absent. Table 9.154A should not be used for clay till which would have an equivalent fluid density greater than 480 kg/m^3.

This study has verified that different soil types exhibit different equivalent fluid densities consistent with the literature. Therefore, the recommendations of Table 9.15.4A should be re-evaluated for other soil types having characteristically higher equivalent densities. The table of acceptable backfill heights should also address conditions where water pressures may act on the walls, in addition to the soil pressures. This condition could be encountered where the foundation drainage system or weeping tile becomes blocked or ineffective during the life of the building.

Table 9.15.4A should not be used to obtain acceptable backfill height for any backfill soil other than clean, free draining granular material.

BIBLIOGRAPHY

Alberta Building Code. 1985. Building Standards Branch, Edmonton, Alberta, Canada.

Canadian Foundation Engineering Manual. 1985. Canadian Geotechnical Society, Montreal, Quebec.

Engineering Design in Wood. 1984. Canadian Standards Association. CSA CAN3-0986.1-M84. Rexdale, Ontario, Canada.

Hunt, R.E. 1986. **Geotechnical Engineering Analysis and Evaluation**. McGraw-Hill, Inc., New York.

Instrumentation Installation and Laboratory Testing, County of Strathcona Foundation Drain Test Site. October 1990. EBA Engineering Consultants Limited. Report to CH2M Hill Engineering Limited. EBA Report: 0106-10455.

Lambe, T.W., and Whitman, R.V. 1979. **Soil Mechanics**. John Wiley & Sons, New York.

Peck, R.B., Hanson, W.E., and Thornburn, T.H. 1974. **Foundation Engineering**. John Wiley & Sons, Inc., New York.

Terzaghi, K., and Peck, R.P. 1967. **Soil Mechanics in Engineering Practice**. John Wiley & Sons, New York.

Thin Wall Foundation. 1990. University of Alberta, Department of Civil Engineering, Edmonton, Alberta. Final Report to Alberta Municipal Affairs, Housing Division.

APPENDIX A
CONSTRUCTION DRAWINGS

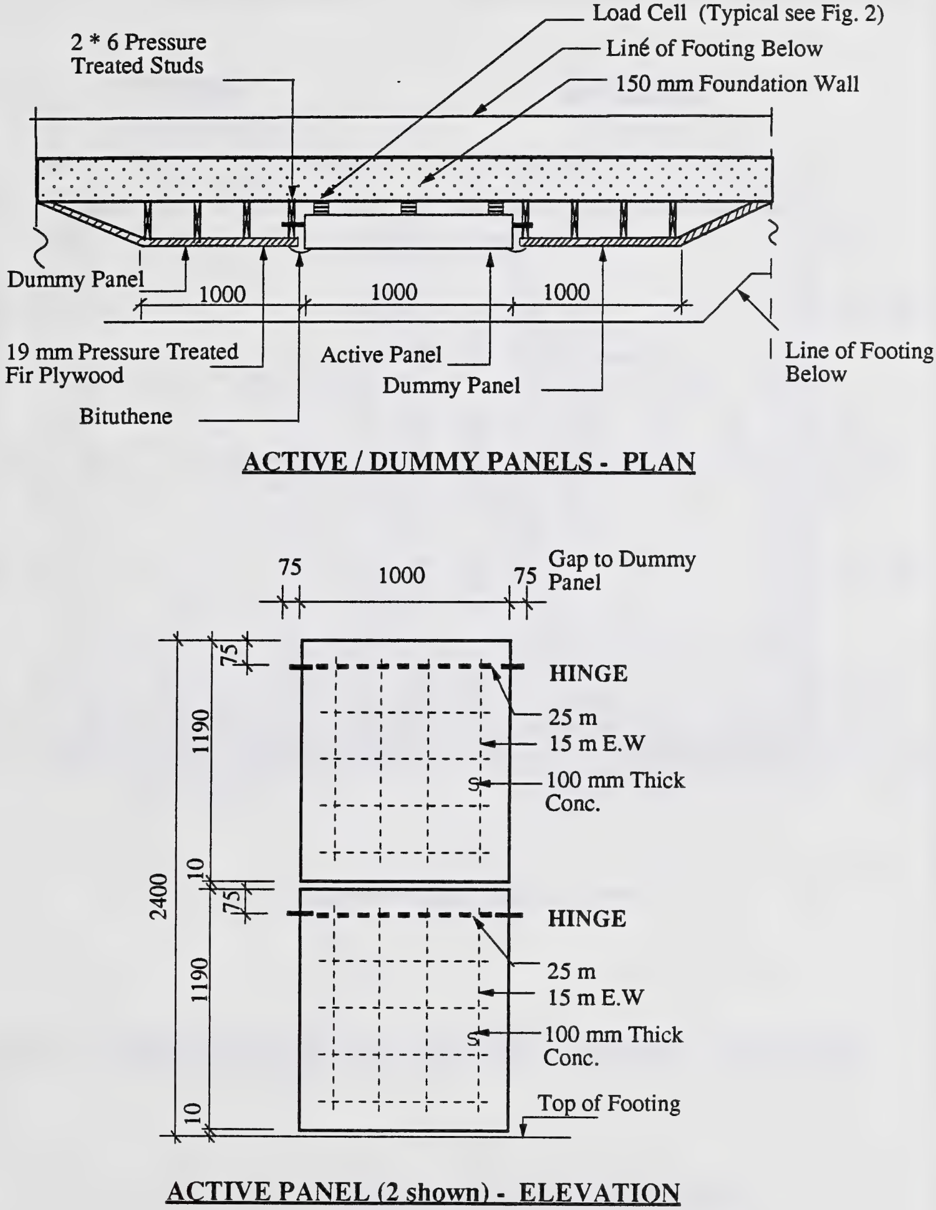


Figure 1. Test Panel Arrangement

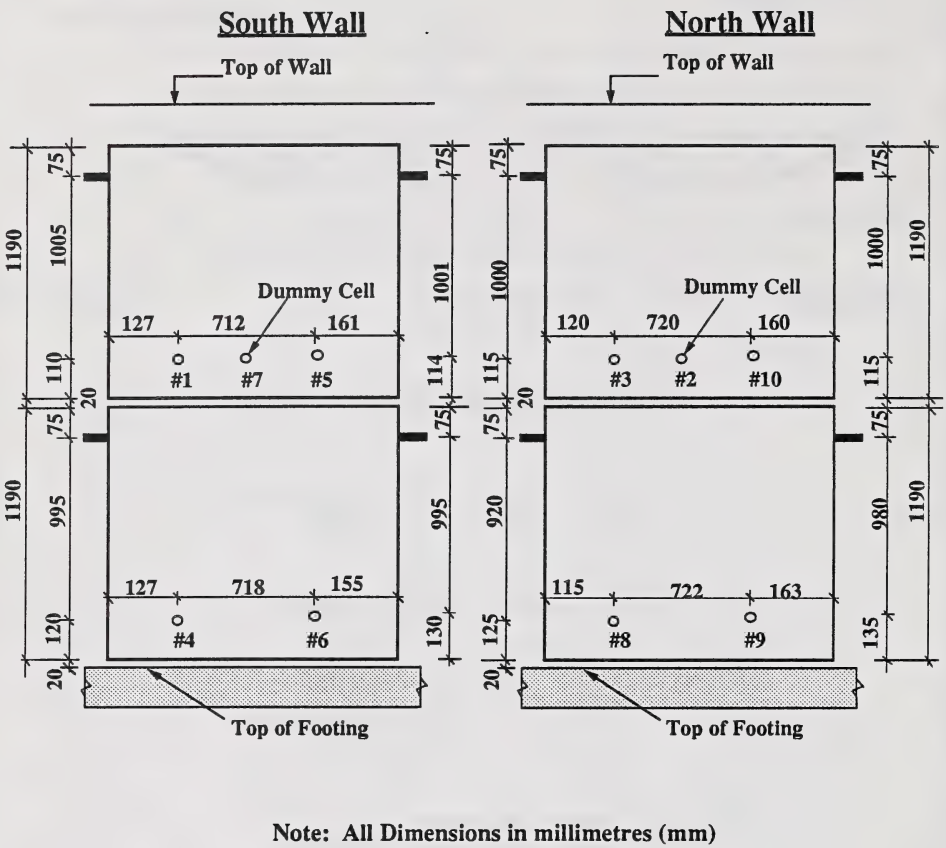


Figure 2. Location of Load Cells Behind Active Panels

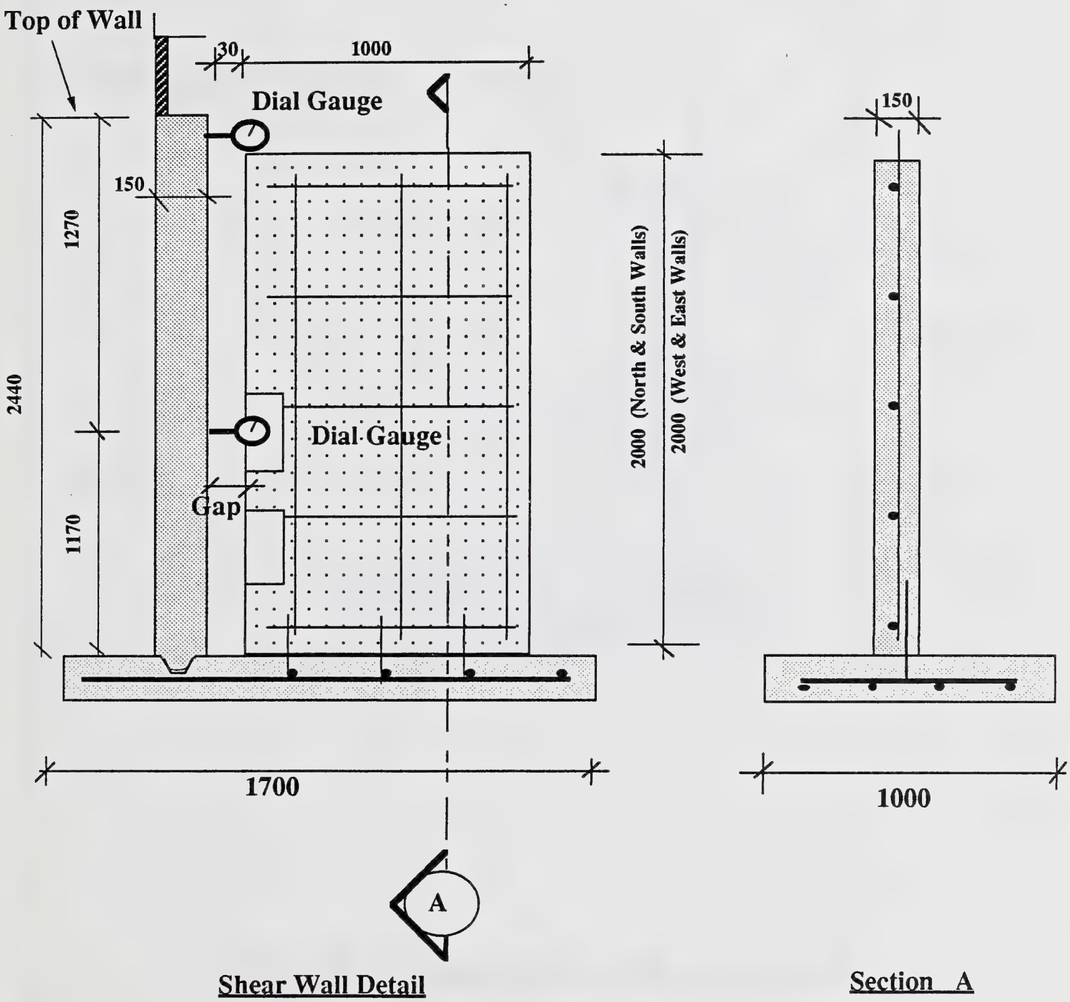


Figure 3 Shear Wall Details and Locations of Deflection Dial Gauges

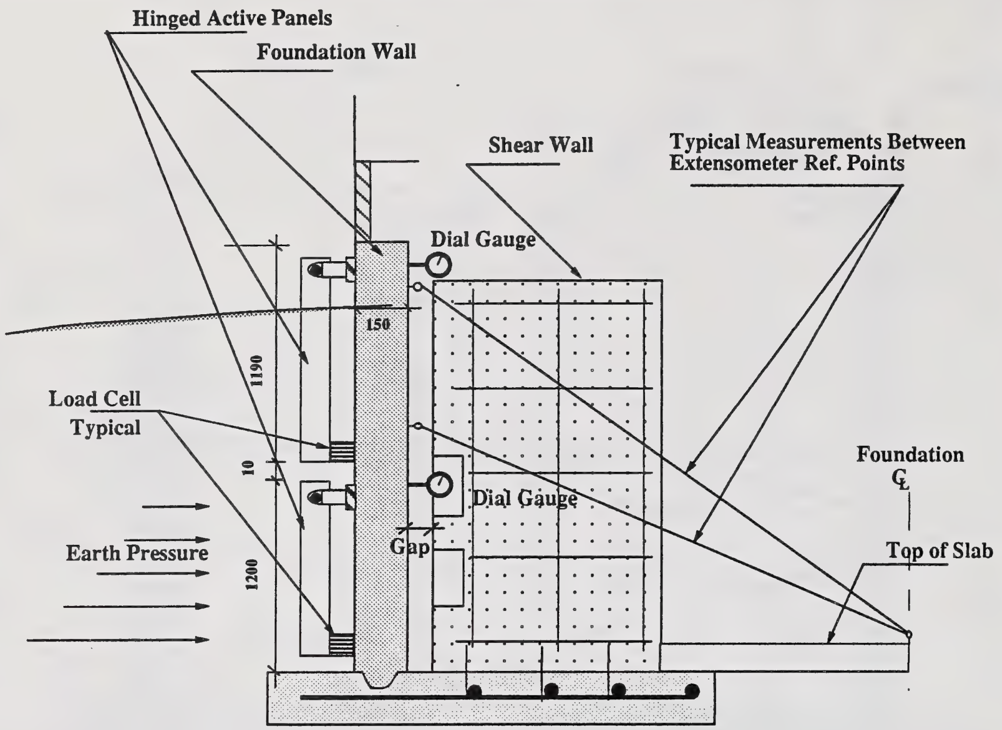


Figure 4 Data Measuring System

APPENDIX B
REDUCED FIELD DATA SHEETS

THIN WALL FOUNDATION TESTING

Initial Rdg Date:27/NOV/90		Final Rdg Date:27/NOV/90		
NORTH WALL		**NORTH WALL**		
Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	5129	7.00
TR 10	1158	TR 10	1037	121.00
D 2	2540	D 2	2539	1.00
BL 8	6379	BL 8	6250	129.00
BR 9	1715	BR 9	1570	145.00
South Wall		**South Wall**		
TL 1	3060	TL 1	2744	316.00
TR 5	616	TR 5	554	62.00
D 7	2332	D 7	2328	4.00
BL 4	8471	BL 4	8435	36.00
BR 6	5600	BR 6	5260	340.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (KN)
TL 3	0.10
TR 10	0.38
D 2	0.07
BL 8	0.88
BR 9	0.78

South Wall

Load Cell No.	Total Load (KN)
TL 1	1.80
TR 5	0.45
D 7	0.04
BL 4	0.26
BR 6	2.20

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.77 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.40	0.80
LOWER PANEL	1.39	1.98

SOUTH WALL

Backfill Ht: 1.97 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.89	3.78
LOWER PANEL	2.06	0.35

THIN WALL FOUNDATION TESTING

Initial Rdg Date:27/NOV/90	Final Rdg Date:26/APRIL/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	5067	69.00
TR 10	1158	TR 10	992	166.00
D 2	2540	D 2	2538	2.00
BL 8	6379	BL 8	5758	621.00
BR 9	1715	BR 9	1595	120.00

South Wall

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	3060	TL 1	2952	108.00
TR 5	616	TR 5	578	38.00
D 7	2332	D 7	2318	14.00
BL 4	8471	BL 4	8335	136.00
BR 6	5600	BR 6	5080	520.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.52
TR 10	0.58
D 2	0.06
BL 8	3.87
BR 9	0.63

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.59
TR 5	0.28
D 7	0.01
BL 4	0.92
BR 6	3.29

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.48 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.93	1.85
LOWER PANEL	3.78	5.71

SOUTH WALL

Backfill Ht: 1.37 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.73	1.47
LOWER PANEL	3.53	5.60

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

Final
Rdg Date:30/APRIL/91

NORTH WALL

Load Cell No.		Strain Reading (ue) initial	Strain Reading (ue) final	Strain Difference (ue)
TL	3	5136	5091	45.00
TR	10	1158	1081	77.00
D	2	2540	2538	2.00
BL	8	6379	5795	584.00
BR	9	1715	1650	65.00

South Wall

Load Cell No.		Strain Reading (ue) initial	Strain Reading (ue) final	Strain Difference (ue)
TL	1	3060	3006	54.00
TR	5	616	650	34.00
D	7	2332	2321	11.00
BL	4	8471	8344	127.00
BR	6	5600	5079	521.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.		Total Load (kN)
TL	3	0.36
TR	10	0.18
D	2	0.06
BL	8	3.66
BR	9	0.32

South Wall

Load Cell No.		Total Load (kN)
TL	1	0.28
TR	5	0.25
D	7	0.01
BL	4	0.86
BR	6	3.30

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.48 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.45	0.91
LOWER PANEL	3.34	5.78

SOUTH WALL

Backfill Ht: 1.37 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.45	0.90
LOWER PANEL	3.49	6.08

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

Final
Rdg Date:1/MAY/91

NORTH WALL

Load Cell No.	Strain Reading (ue) (Initial)	Strain Reading (ue) (Final)	Strain Difference (ue)
TL 3	5136	5048	88.00
TR 10	1158	1033	125.00
D 2	2540	2534	6.00
BL 8	6379	5770	609.00
BR 9	1715	1605	110.00

South Wall

Load Cell No.	Strain Reading (ue) (Initial)	Strain Reading (ue) (Final)	Strain Difference (ue)
TL 1	3060	2954	106.00
TR 5	616	671	55.00
D 7	2332	2321	11.00
BL 4	8471	8334	137.00
BR 6	5600	5078	522.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.64
TR 10	0.40
D 2	0.04
BL 8	3.80
BR 9	0.58

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.58
TR 5	0.40
D 7	0.01
BL 4	0.92
BR 6	3.30

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.87	1.75
LOWER PANEL	3.68	5.61

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.82	1.65
LOWER PANEL	3.55	5.45

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.		Strain Reading (ue)
TL	3	5136
TR	10	1158
D	2	2540
BL	8	6379
BR	9	1715

South Wall

TL	1	3060
TR	5	616
D	7	2332
BL	4	8471
BR	6	5600

Final
Rdg Date:2/MAY/91

NORTH WALL

Load Cell No.		Strain Reading (ue)	Strain Difference (ue)
TL	3	5080	56.00
TR	10	1060	98.00
D	2	2536	4.00
BL	8	5760	619.00
BR	9	1631	84.00

South Wall

TL	1	2993	67.00
TR	5	502	114.00
D	7	2324	8.00
BL	4	8377	94.00
BR	6	5067	533.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.		Total Load (kN)
TL	3	0.43
TR	10	0.27
D	2	0.05
BL	8	3.86
BR	9	0.43

South Wall

TL	1	0.36
TR	5	0.82
D	7	0.02
BL	4	0.64
BR	6	3.37

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.59	1.18
LOWER PANEL	3.60	6.02

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.99	1.97
LOWER PANEL	3.37	4.76

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5136
TR 10	1158
D 2	2540
BL 8	6379
BR 9	1715

South Wall

Load Cell No.	Strain Reading (ue)
TL 1	3060
TR 5	616
D 7	2332
BL 4	8471
BR 6	5600

Final
Rdg Date:21/MAY/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5027	109.00
TR 10	1094	64.00
D 2	2530	10.00
BL 8	5926	453.00
BR 9	1532	183.00

South Wall

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	2972	88.00
TR 5	516	100.00
D 7	2302	30.00
BL 4	8400	71.00
BR 6	5156	444.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.78
TR 10	0.13
D 2	0.02
BL 8	2.90
BR 9	1.00

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.48
TR 5	0.72
D 7	0.08
BL 4	0.49
BR 6	2.84

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.76	1.53
LOWER PANEL	3.28	5.03

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.01	2.01
LOWER PANEL	2.79	3.58

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5136
TR 10	1158
D 2	2540
BL 8	6379
BR 9	1715

South Wall

Load Cell No.	Strain Reading (ue)
TL 1	3060
TR 5	616
D 7	2332
BL 4	8471
BR 6	5600

Final
Rdg Date:29/MAY/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	4946	190.00
TR 10	1143	15.00
D 2	2529	11.00
BL 8	5880	499.00
BR 9	1556	159.00

South Wall

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	2961	99.00
TR 5	518	98.00
D 7	2291	41.00
BL 4	8378	93.00
BR 6	5165	435.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.31
TR 10	0.08
D 2	0.01
BL 8	3.17
BR 9	0.86

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.54
TR 5	0.70
D 7	0.13
BL 4	0.63
BR 6	2.78

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.17	2.34
LOWER PANEL	3.39	4.44

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.05	2.09
LOWER PANEL	2.87	3.65

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

Final
Rdg Date:4/JUNE/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	4893	243.00
TR 10	1158	TR 10	1122	36.00
D 2	2540	D 2	2497	43.00
BL 8	6379	BL 8	5837	542.00
BR 9	1715	BR 9	1544	171.00

South Wall

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	3060	TL 1	2885	175.00
TR 5	616	TR 5	472	144.00
D 7	2332	D 7	2244	88.00
BL 4	8471	BL 4	8317	154.00
BR 6	5600	BR 6	5146	454.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.65
TR 10	0.01
D 2	0.17
BL 8	3.42
BR 9	0.93

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.98
TR 5	1.02
D 7	0.34
BL 4	1.03
BR 6	2.90

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.39	2.78
LOWER PANEL	3.66	4.53

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.68	3.37
LOWER PANEL	3.30	3.24

THIN WALL FOUNDATION TESTING

Initial Rdg Date:27/NOV/90		Final Rdg Date:13/JUNE/91		
NORTH WALL		**NORTH WALL**		
Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	5005	131.00
TR 10	1158	TR 10	1179	21.00
D 2	2540	D 2	2569	29.00
BL 8	6379	BL 8	5931	448.00
BR 9	1715	BR 9	1587	128.00
South Wall		**South Wall**		
TL 1	3060	TL 1	2920	140.00
TR 5	616	TR 5	563	53.00
D 7	2332	D 7	2303	29.00
BL 4	8471	BL 4	8424	47.00
BR 6	5600	BR 6	5274	326.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.93
TR 10	0.06
D 2	0.09
BL 8	2.87
BR 9	0.68

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.78
TR 5	0.39
D 7	0.07
BL 4	0.33
BR 6	2.11

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.83	1.65
LOWER PANEL	2.99	4.32

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.98	1.95
LOWER PANEL	2.05	2.15

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5136
TR 10	1158
D 2	2540
BL 8	6379
BR 9	1715

South Wall

TL 1	3060
TR 5	616
D 7	2332
BL 4	8471
BR 6	5600

Final
Rdg Date:20/JUNE/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	4958	178.00
TR 10	1129	29.00
D 2	2526	14.00
BL 8	5886	493.00
BR 9	1584	131.00

South Wall

TL 1	2865	195.00
TR 5	507	109.00
D 7	2256	76.00
BL 4	8344	127.00
BR 6	5232	368.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.23
TR 10	0.02
D 2	0.01
BL 8	3.14
BR 9	0.70

South Wall

TL 1	1.09
TR 5	0.78
D 7	0.29
BL 4	0.86
BR 6	2.37

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.05	2.11
LOWER PANEL	3.22	4.34

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.58	3.15
LOWER PANEL	2.71	2.28

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5136
TR 10	1158
D 2	2540
BL 8	6379
BR 9	1715

South Wall

TL 1	3060
TR 5	616
D 7	2332
BL 4	8471
BR 6	5600

Final
Rdg Date:24/JUNE/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	4875	261.00
TR 10	1101	57.00
D 2	2486	54.00
BL 8	5784	595.00
BR 9	1541	174.00

South Wall

TL 1	2813	247.00
TR 5	536	80.00
D 7	2229	103.00
BL 4	8257	214.00
BR 6	5228	372.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.76
TR 10	0.10
D 2	0.24
BL 8	3.72
BR 9	0.94

South Wall

TL 1	1.40
TR 5	0.58
D 7	0.41
BL 4	1.42
BR 6	2.40

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.56	3.12
LOWER PANEL	3.92	4.73

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.66	3.32
LOWER PANEL	3.21	3.11

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

Final
Rdg Date:11/JULY/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	4930	206.00
TR 10	1158	TR 10	1102	56.00
D 2	2540	D 2	2503	37.00
BL 8	6379	BL 8	5845	534.00
BR 9	1715	BR 9	1555	160.00

South Wall

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	3060	TL 1	2802	258.00
TR 5	616	TR 5	561	55.00
D 7	2332	D 7	2262	70.00
BL 4	8471	BL 4	8327	144.00
BR 6	5600	BR 6	5317	283.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.41
TR 10	0.09
D 2	0.14
BL 8	3.38
BR 9	0.86

South Wall

Load Cell No.	Total Load (kN)
TL 1	1.46
TR 5	0.40
D 7	0.26
BL 4	0.97
BR 6	1.85

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.26	2.52
LOWER PANEL	3.56	4.60

SOUTH WALL

Backfill Ht: 1.60 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.56	3.13
LOWER PANEL	2.37	1.61

THIN WALL FOUNDATION TESTING

Initial Rdg Date:27/NOV/90		Final Rdg Date:25/JULY/91		
NORTH WALL		**NORTH WALL**		
Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	4920	216.00
TR 10	1158	TR 10	1108	50.00
D 2	2540	D 2	2503	37.00
BL 8	6379	BL 8	5855	524.00
BR 9	1715	BR 9	1501	214.00
South Wall		**South Wall**		
TL 1	3060	TL 1	2781	279.00
TR 5	616	TR 5	560	56.00
D 7	2332	D 7	2263	69.00
BL 4	8471	BL 4	8248	223.00
BR 6	5600	BR 6	5279	321.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	1.47
TR 10	0.07
D 2	0.14
BL 8	3.32
BR 9	1.18

South Wall

Load Cell No.	Total Load (kN)
TL 1	1.58
TR 5	0.41
D 7	0.26
BL 4	1.48
BR 6	2.08

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.40 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.29	2.59
LOWER PANEL	3.78	4.97

SOUTH WALL

Backfill Ht: 1.40 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.67	3.34
LOWER PANEL	3.00	2.65

THIN WALL FOUNDATION TESTING

Initial		Final		
Rdg Date:27/NOV/90		Rdg Date:7/AUG/91		

NORTH WALL

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	4816	320.00
TR 10	1158	TR 10	1062	96.00
D 2	2540	D 2	2498	42.00
BL 8	6379	BL 8	5826	553.00
BR 9	1715	BR 9	1489	226.00

South Wall

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	3060	TL 1	2655	405.00
TR 5	616	TR 5	450	166.00
D 7	2332	D 7	2259	73.00
BL 4	8471	BL 4	8240	231.00
BR 6	5600	BR 6	5314	286.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	2.12
TR 10	0.27
D 2	0.17
BL 8	3.49
BR 9	1.25

South Wall

Load Cell No.	Total Load (kN)
TL 1	2.32
TR 5	1.17
D 7	0.27
BL 4	1.53
BR 6	1.86

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.75 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	2.01	4.02
LOWER PANEL	3.98	3.94

SOUTH WALL

Backfill Ht: 1.90 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	2.94	5.87
LOWER PANEL	2.86	-0.16

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:27/NOV/90

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5136
TR 10	1158
D 2	2540
BL 8	6379
BR 9	1715

South Wall

Load Cell No.	Strain Reading (ue)
TL 1	3060
TR 5	616
D 7	2332
BL 4	8471
BR 6	5600

Final
Rdg Date:13/AUG/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	4821	315.00
TR 10	1065	93.00
D 2	2499	41.00
BL 8	5831	548.00
BR 9	1499	216.00

South Wall

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	2655	405.00
TR 5	459	157.00
D 7	2257	75.00
BL 4	8238	233.00
BR 6	5314	286.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	2.09
TR 10	0.25
D 2	0.16
BL 8	3.46
BR 9	1.19

South Wall

Load Cell No.	Total Load (kN)
TL 1	2.32
TR 5	1.11
D 7	0.28
BL 4	1.55
BR 6	1.86

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.75 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.97	3.94
LOWER PANEL	3.90	3.86

SOUTH WALL

Backfill Ht: 1.90 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	2.88	5.77
LOWER PANEL	2.87	-0.03

THIN WALL FOUNDATION TESTING

Initial Rdg Date:27/NOV/90		Final Rdg Date:19/AUG/91		
NORTH WALL		**NORTH WALL**		
Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5136	TL 3	4767	369.00
TR 10	1158	TR 10	1026	132.00
D 2	2540	D 2	2483	57.00
BL 8	6379	BL 8	5813	566.00
BR 9	1715	BR 9	1449	266.00
South Wall		**South Wall**		
TL 1	3060	TL 1	2588	472.00
TR 5	616	TR 5	374	242.00
D 7	2332	D 7	2255	77.00
BL 4	8471	BL 4	8195	276.00
BR 6	5600	BR 6	5324	276.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	2.42
TR 10	0.43
D 2	0.25
BL 8	3.56
BR 9	1.48

South Wall

Load Cell No.	Total Load (kN)
TL 1	2.71
TR 5	1.69
D 7	0.29
BL 4	1.82
BR 6	1.80

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.75 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	2.39	4.79
LOWER PANEL	4.23	3.68

SOUTH WALL

Backfill Ht: 1.90 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	3.70	7.40
LOWER PANEL	3.05	-1.30

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:21/AUG/91

NORTH WALL

Load Cell No.		Strain Reading (ue)
TL	3	5068
TR	10	1094
D	2	2476
BL	8	6325
BR	9	1640

South Wall

TL	1	2940
TR	5	535
D	7	2257
BL	4	8329
BR	6	5628

Final
Rdg Date:23/AUG/91

NORTH WALL

Load Cell No.		Strain Reading (ue)	Strain Difference (ue)
TL	3	4957	111.00
TR	10	1093	1.00
D	2	2479	3.00
BL	8	6064	261.00
BR	9	1586	54.00

South Wall

TL	1	2774	166.00
TR	5	533	2.00
D	7	2257	0.00
BL	4	8181	148.00
BR	6	5416	212.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.		Total Load (kN)
TL	3	0.80
TR	10	0.14
D	2	0.06
BL	8	1.73
BR	9	0.25

South Wall

TL	1	0.93
TR	5	0.02
D	7	0.06
BL	4	0.99
BR	6	1.40

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.70 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.79	1.57
LOWER PANEL	1.67	1.76

SOUTH WALL

Backfill Ht: 1.70 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.80	1.59
LOWER PANEL	2.01	2.43

THIN WALL FOUNDATION TESTING

Initial	Final
Rdg Date:21/AUG/91	Rdg Date:29/AUG/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5068	TL 3	5037	31.00
TR 10	1094	TR 10	1097	3.00
D 2	2476	D 2	2477	1.00
BL 8	6325	BL 8	6038	287.00
BR 9	1640	BR 9	1560	80.00

South Wall

Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 1	2940	TL 1	2811	129.00
TR 5	535	TR 5	530	5.00
D 7	2257	D 7	2255	2.00
BL 4	8329	BL 4	7979	350.00
BR 6	5628	BR 6	5126	502.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.26
TR 10	0.13
D 2	0.07
BL 8	1.89
BR 9	0.40

South Wall

Load Cell No.	Total Load (kN)
TL 1	0.71
TR 5	0.04
D 7	0.05
BL 4	2.30
BR 6	3.18

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.50 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.33	0.66
LOWER PANEL	1.93	3.20

SOUTH WALL

Backfill Ht: 1.50 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.63	1.27
LOWER PANEL	4.60	7.94

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:21/AUG/91

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5068
TR 10	1094
D 2	2476
BL 8	6325
BR 9	1640

South Wall

TL 1	2940
TR 5	535
D 7	2257
BL 4	8329
BR 6	5628

Final
Rdg Date:9/SEPT/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5058	10.00
TR 10	1092	2.00
D 2	2471	5.00
BL 8	5798	527.00
BR 9	1496	144.00

South Wall

TL 1	2814	126.00
TR 5	524	11.00
D 7	2253	4.00
BL 4	7881	448.00
BR 6	5083	545.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (kN)
TL 3	0.12
TR 10	0.13
D 2	0.05
BL 8	3.34
BR 9	0.77

South Wall

TL 1	0.70
TR 5	0.08
D 7	0.04
BL 4	2.91
BR 6	3.44

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Clay

NORTH WALL

Backfill Ht: 1.50 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.21	0.43
LOWER PANEL	3.45	6.47

SOUTH WALL

Backfill Ht: 1.50 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.66	1.31
LOWER PANEL	5.34	9.36

THIN WALL FOUNDATION TESTING

Initial Rdg Date:10/SEPT/91		Final Rdg Date:11/SEPT/91		
NORTH WALL		**NORTH WALL**		
Load Cell No.	Strain Reading (ue)	Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5068	TL 3	5065	3.00
TR 10	1094	TR 10	1093	1.00
D 2	2476	D 2	2473	3.00
BL 8	6325	BL 8	5815	510.00
BR 9	1640	BR 9	1509	131.00
South Wall		**South Wall**		
TL 1	2932	TL 1	2720	212.00
TR 5	526	TR 5	388	138.00
D 7	2253	D 7	2256	3.00
BL 4	8308	BL 4	7955	353.00
BR 6	5631	BR 6	5192	439.00

PANEL LOADS DUE TO SOIL BACKFILL

Load Cell No.	Total Load (KN)
NORTH WALL	
TL 3	0.07
TR 10	0.14
D 2	0.06
BL 8	3.24
BR 9	0.70
South Wall	
TL 1	1.19
TR 5	0.98
D 7	0.04
BL 4	2.31
BR 6	2.80

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Sand

NORTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.18	0.36
LOWER PANEL	3.31	6.26

SOUTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.83	3.66
LOWER PANEL	4.30	4.95

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:10/SEPT/91

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5068
TR 10	1094
D 2	2476
BL 8	6325
BR 9	1640

South Wall

TL 1	2932
TR 5	526
D 7	2253
BL 4	8308
BR 6	5631

Final
Rdg Date:19/SEPT/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5057	11.00
TR 10	1090	4.00
D 2	2469	7.00
BL 8	5853	472.00
BR 9	1448	192.00

South Wall

TL 1	2807	125.00
TR 5	490	36.00
D 7	2251	2.00
BL 4	7886	422.00
BR 6	5269	362.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (KN)
TL 3	0.13
TR 10	0.13
D 2	0.03
BL 8	3.02
BR 9	1.05

South Wall

TL 1	0.69
TR 5	0.26
D 7	0.05
BL 4	2.75
BR 6	2.34

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Sand

NORTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.21	0.43
LOWER PANEL	3.42	6.40

SOUTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.80	1.61
LOWER PANEL	4.27	6.94

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:10/SEPT/91

NORTH WALL

Load Cell No.	Strain Reading (ue)
TL 3	5068
TR 10	1094
D 2	2476
BL 8	6325
BR 9	1640

South Wall

TL 1	2932
TR 5	526
D 7	2253
BL 4	8308
BR 6	5631

Final
Rdg Date:27/SEPT/91

NORTH WALL

Load Cell No.	Strain Reading (ue)	Strain Difference (ue)
TL 3	5056	12.00
TR 10	1091	3.00
D 2	2467	9.00
BL 8	5851	474.00
BR 9	1448	192.00

South Wall

TL 1	2800	132.00
TR 5	464	62.00
D 7	2250	3.00
BL 4	7857	451.00
BR 6	5176	455.00

PANEL LOADS DUE TO SOIL BACKFILL

NORTH WALL

Load Cell No.	Total Load (KN)
TL 3	0.13
TR 10	0.13
D 2	0.02
BL 8	3.03
BR 9	1.05

South Wall

TL 1	0.73
TR 5	0.45
D 7	0.04
BL 4	2.93
BR 6	2.90

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Sand

NORTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.22	0.44
LOWER PANEL	3.43	6.41

SOUTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.99	1.98
LOWER PANEL	4.90	7.82

THIN WALL FOUNDATION TESTING

Initial
Rdg Date:10/SEPT/91

NORTH WALL

Load Cell No.		Strain Reading (ue)
TL	3	5068
TR	10	1094
D	2	2476
BL	8	6325
BR	9	1640

South Wall

TL	1	2932
TR	5	526
D	7	2253
BL	4	8308
BR	6	5631

Final
Rdg Date:7/OCT/91

NORTH WALL

Load Cell No.		Strain Reading (ue)	Strain Difference (ue)
TL	3	5052	16.00
TR	10	1086	8.00
D	2	2471	5.00
BL	8	5865	460.00
BR	9	1448	192.00

South Wall

TL	1	2801	131.00
TR	5	439	87.00
D	7	2245	8.00
BL	4	7884	424.00
BR	6	5215	416.00

PANEL LOADS DUE
TO SOIL BACKFILL

NORTH WALL

Load Cell No.		Total Load (KN)
TL	3	0.16
TR	10	0.11
D	2	0.05
BL	8	2.95
BR	9	1.05

South Wall

TL	1	0.73
TR	5	0.63
D	7	0.02
BL	4	2.76
BR	6	2.67

SOIL PRESSURE DISTRIBUTIONS

Backfill Type: Sand

NORTH WALL

Backfill Ht: 1.72 m

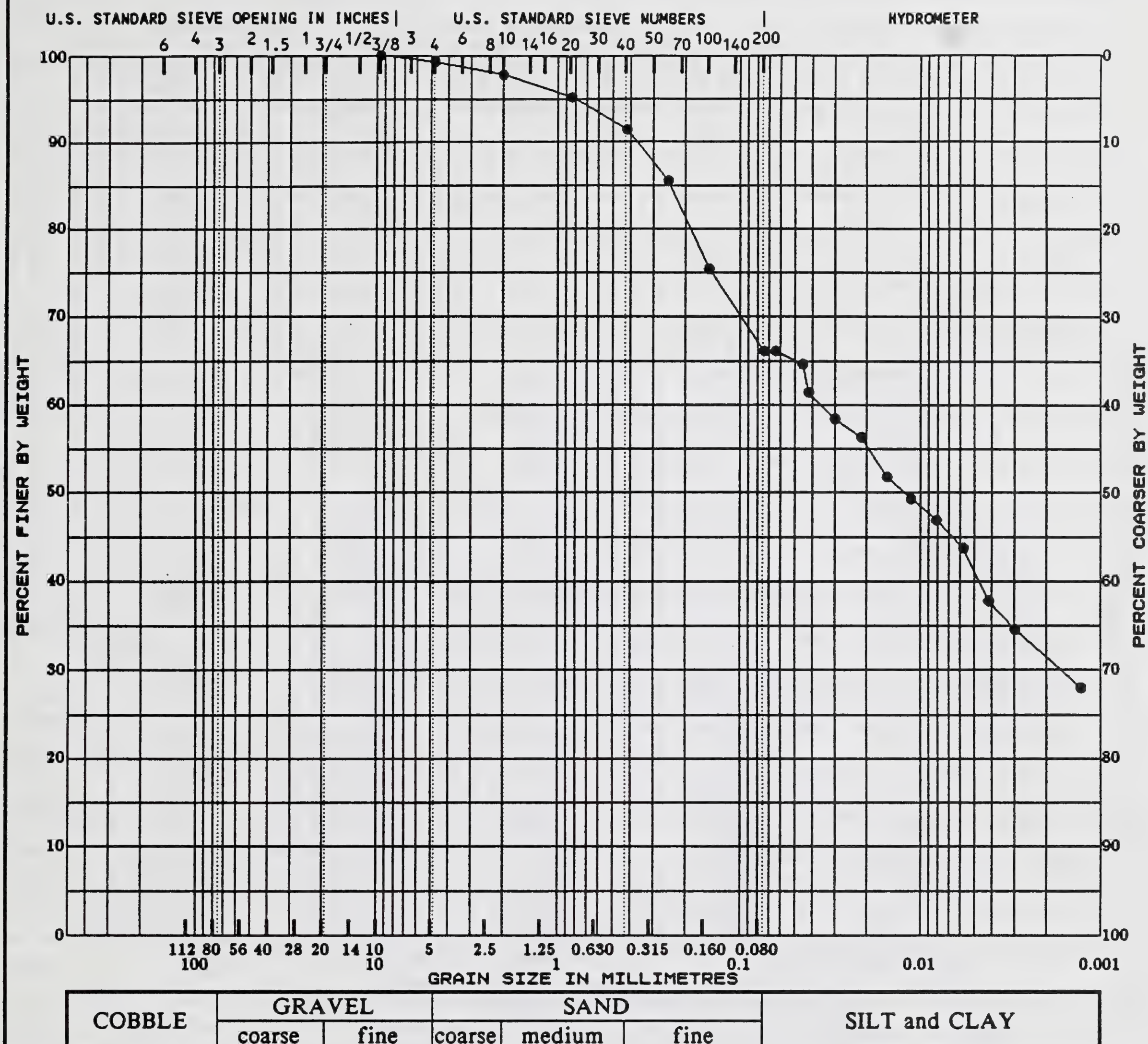
ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	0.23	0.46
LOWER PANEL	3.36	6.26

SOUTH WALL

Backfill Ht: 1.72 m

ASSUMPTION:	UNIFORM (kPa)	TRIANGULAR (kPa)
UPPER PANEL	1.14	2.27
LOWER PANEL	4.56	6.85

APPENDIX C
LABORATORY TEST RESULTS



	Sample	Depth (m)	Description	W%	W_L	W_P	I_P
●	LS1	0.30	Sandy Lean Clay	17.2	50.3	28.7	21.6

	Sample	Depth (m)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	LS1	0.30	9.52	0.04	0.002		0.7	33.0	34.9	31.4

REMARKS:

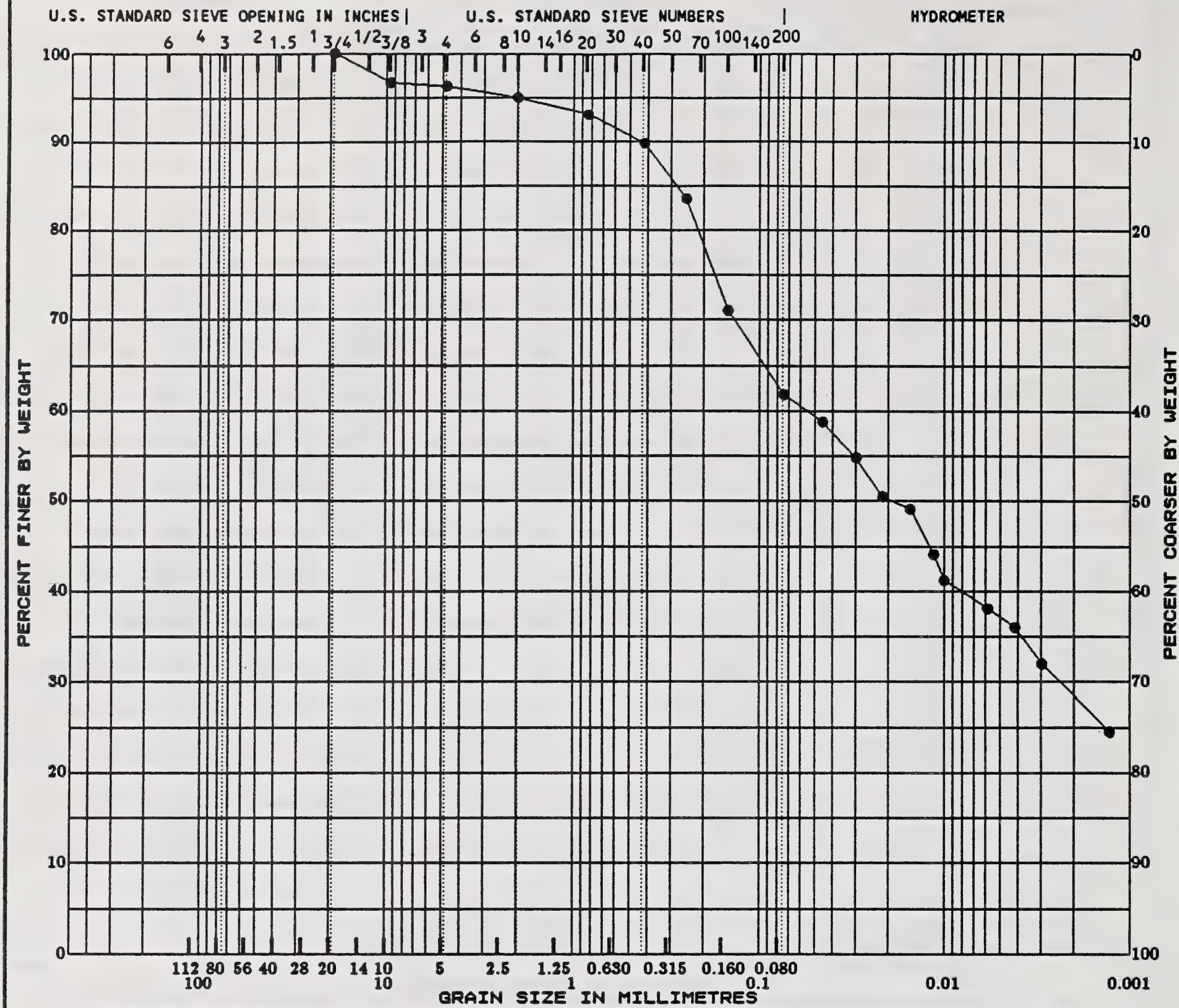
Client: University of Alberta

Project: Thin Wall Foundation

Project No.: ----

Location: Strathcona County
Edmonton, Alberta

GRADATION CURVES



COBBLE	GRAVEL		SAND			SILT and CLAY
	coarse	fine	coarse	medium	fine	

	Sample	Depth (m)	Description	W%	W_L	W_P	I_P
●	SS1	0.30	Sandy Lean Clay	20.8	49.3	30.7	18.6

	Sample	Depth (m)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	SS1	0.30	19.10	0.06	0.002		3.7	34.3	33.6	28.4

REMARKS:

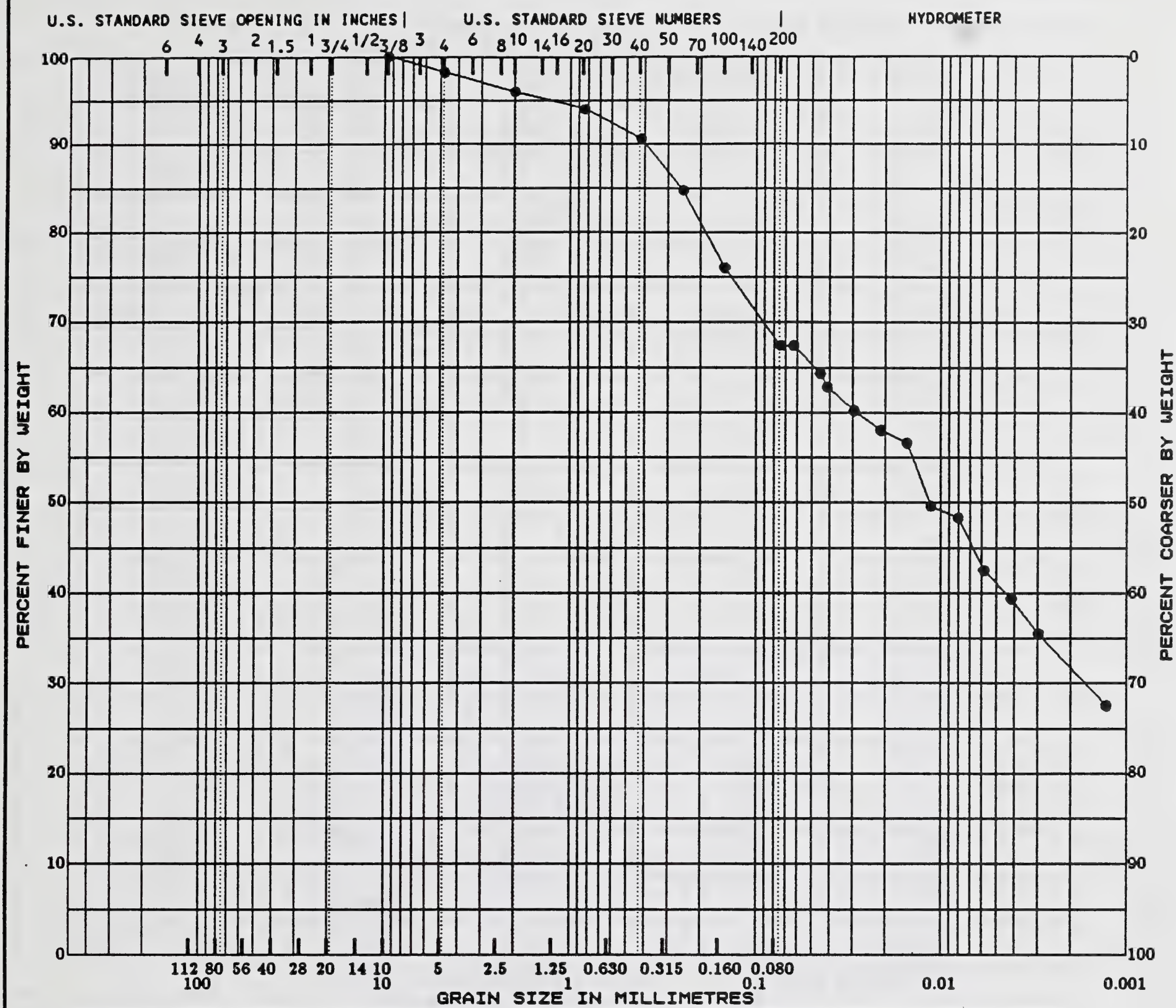
Client: University of Alberta

Project: Thin Wall Foundation

Project No.: ----

Location: Strathcona County
Edmonton, Alberta

GRADATION CURVES



COBBLE	GRAVEL		SAND			SILT and CLAY
	coarse	fine	coarse	medium	fine	

	Sample	Depth (m)	Description	W%	W_L	W_P	I_P
●	BS1	0.15	**Sandy Lean Clay**	20.0	43.2	19.9	23.3

	Sample	Depth (m)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	BS1	0.15	9.52	0.03	0.002		1.8	30.6	35.9	31.6

REMARKS:

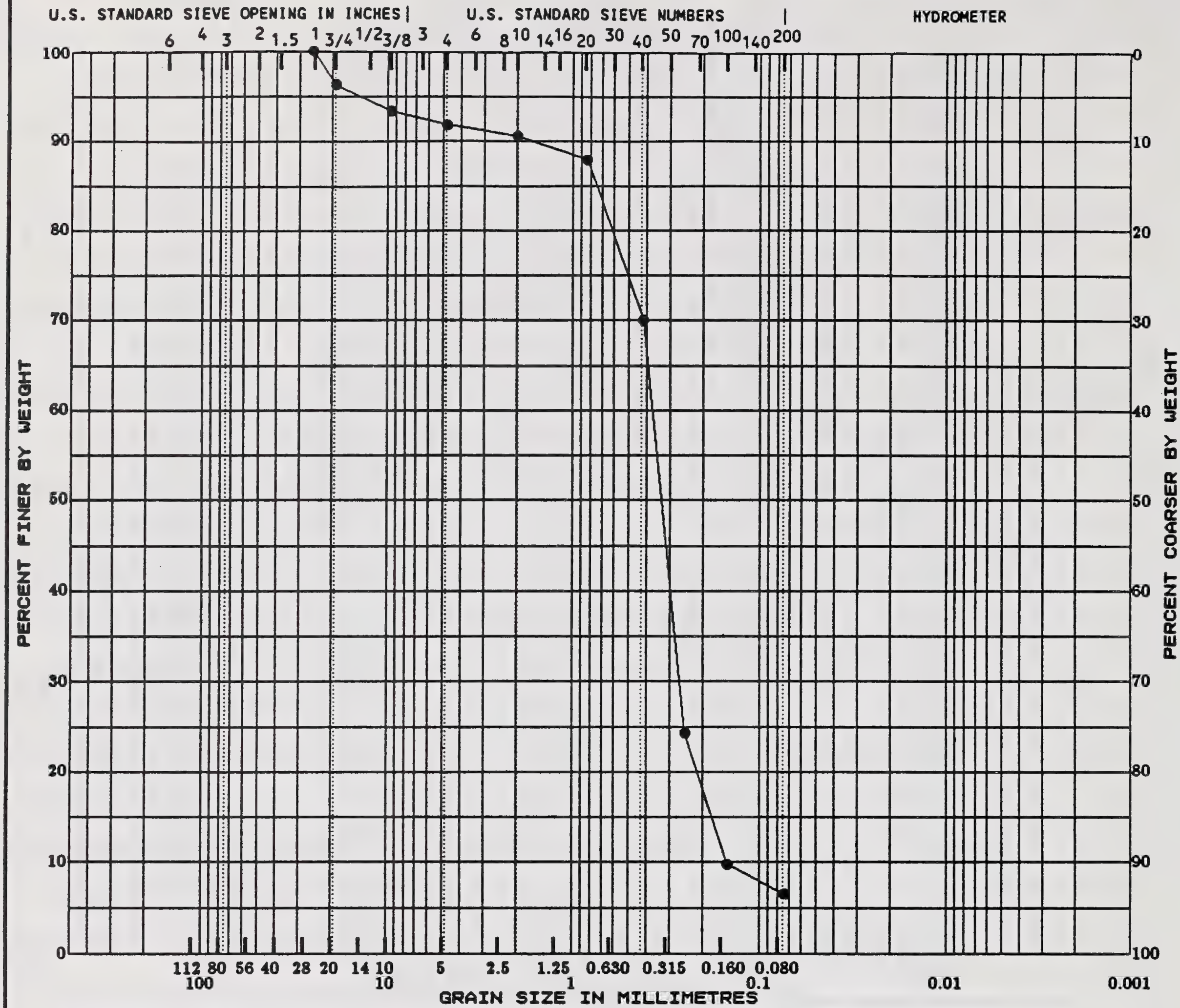
Client: **University of Alberta**

Project: **Thin Wall Foundation**

Project No.: ----

Location: **Strathcona County**
Edmonton, Alberta

GRADATION CURVES



COBBLE	GRAVEL		SAND			SILT and CLAY
	coarse	fine	coarse	medium	fine	

	Sample	Depth (m)	Description	W%	W_L	W_P	I_P
●	BS2	0.30	Sand with occasional Gravel and trace Silt				

	Sample	Depth (m)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	BS2	0.30	25.40	0.37	0.267	0.1501	8.2	85.2	6.6	

REMARKS:

Client:	University of Alberta
Project:	Thin Wall Foundation
Project No.:	----
Location:	Strathcona County Edmonton, Alberta

GRADATION CURVES

APPENDIX D
DATA PLOTS

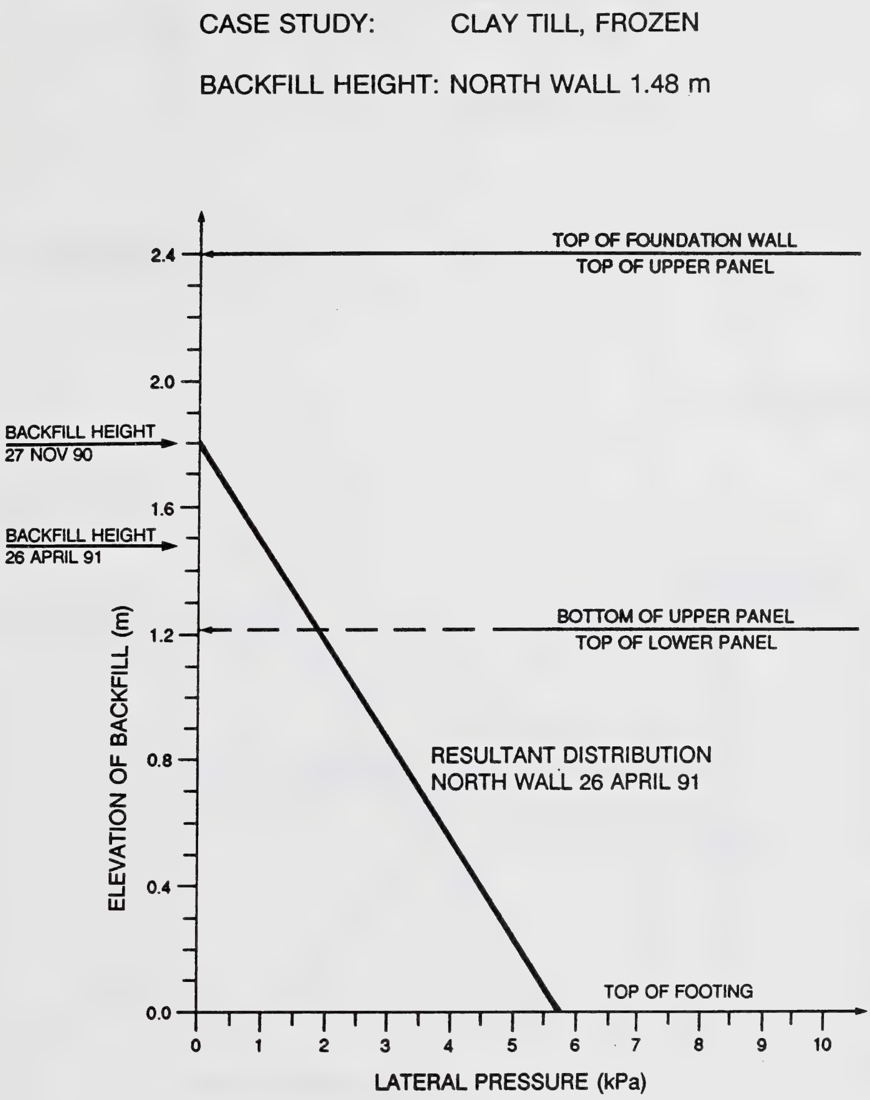


Figure 5. Lateral Pressure vs Elevation of Backfill Clay Till, Frozen

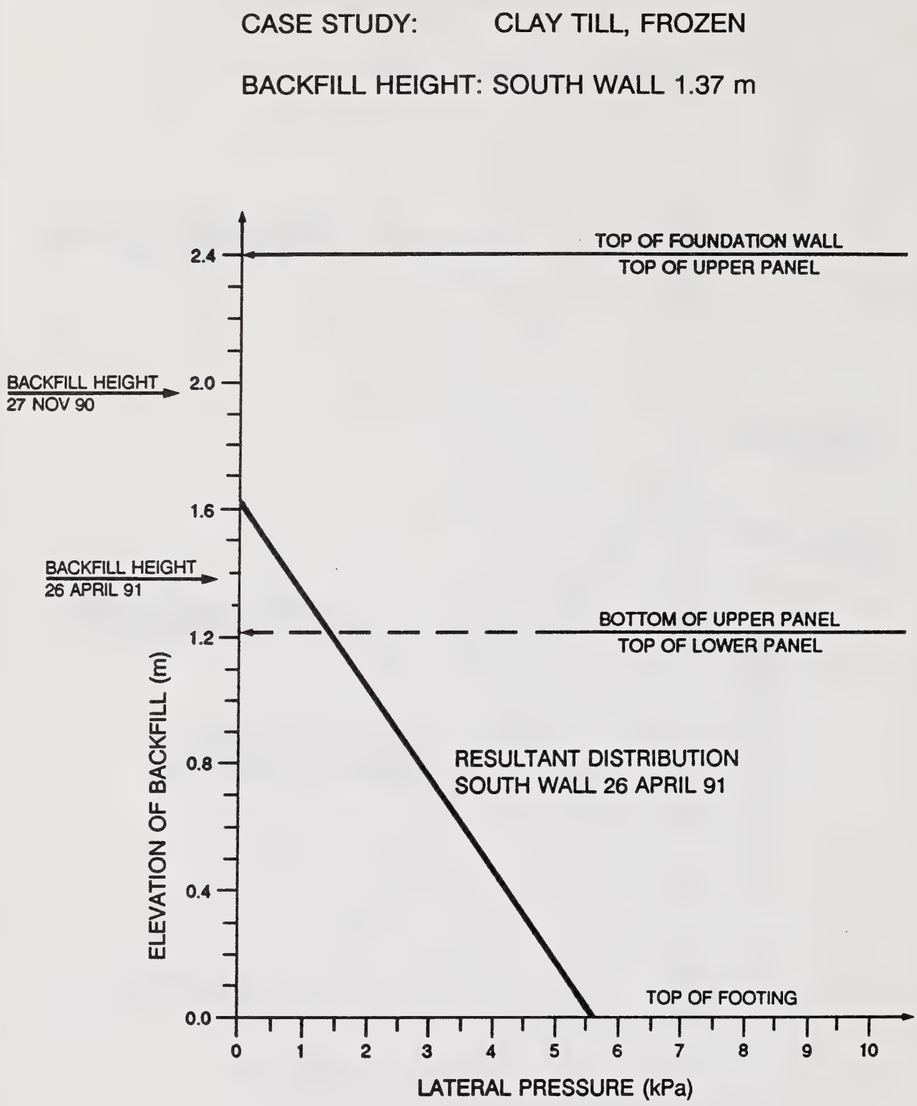


Figure 6. Lateral Pressure vs Elevation of Backfill Clay Till, Frozen

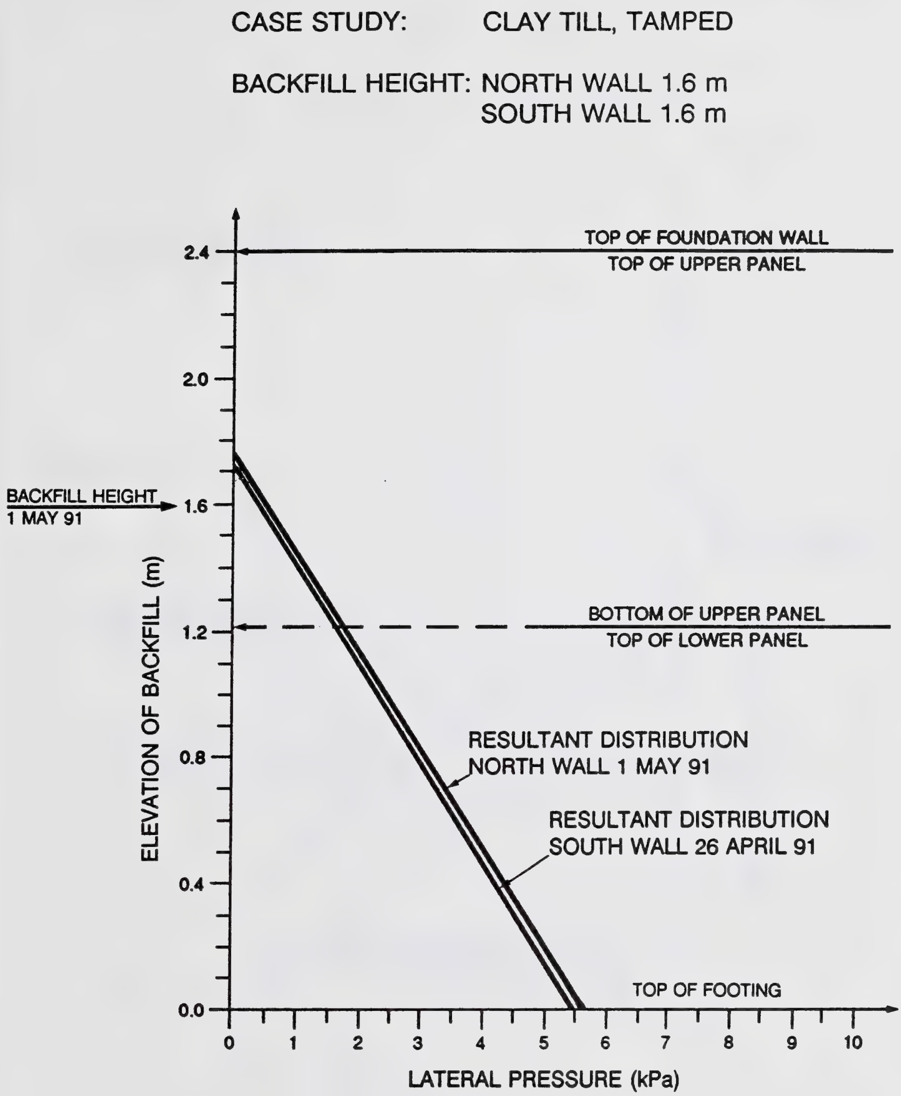


Figure 7. Lateral Pressure vs Elevation of Backfill Clay Till, Tamped

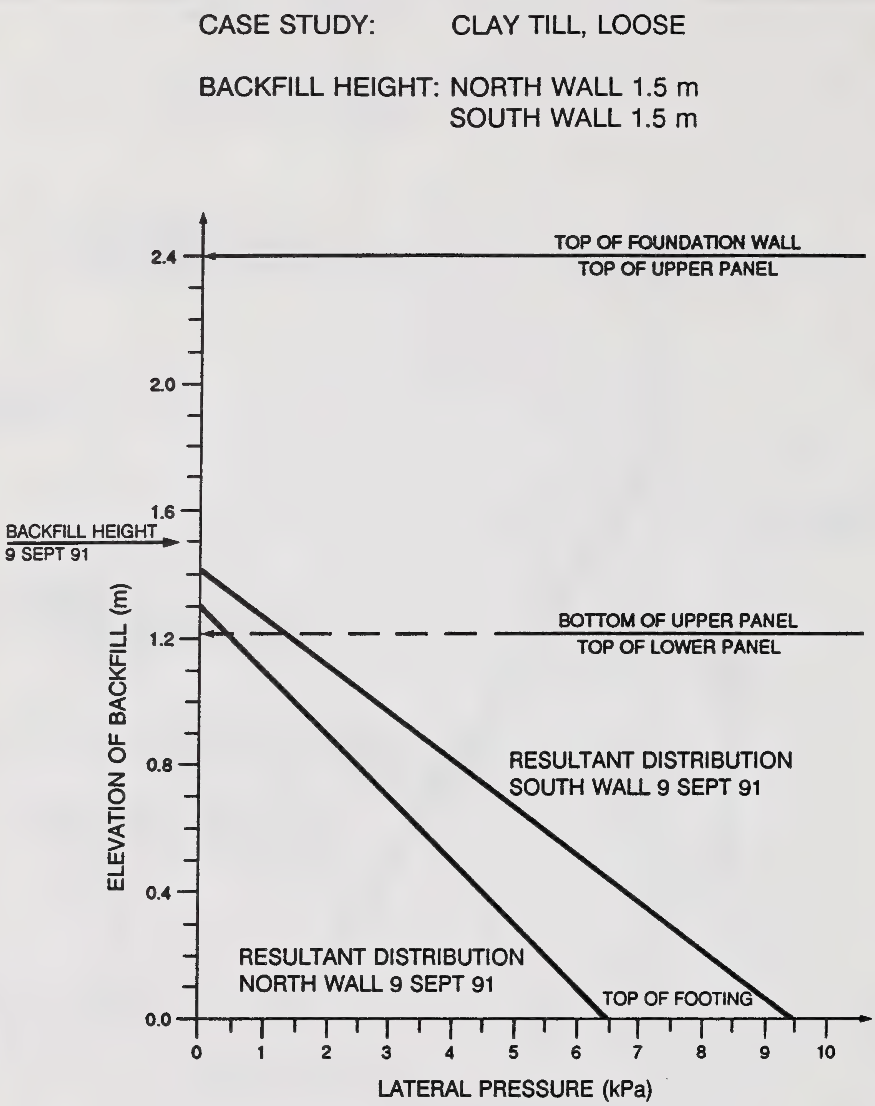


Figure 8. Lateral Pressure vs Elevation of Backfill Clay Till, Loose

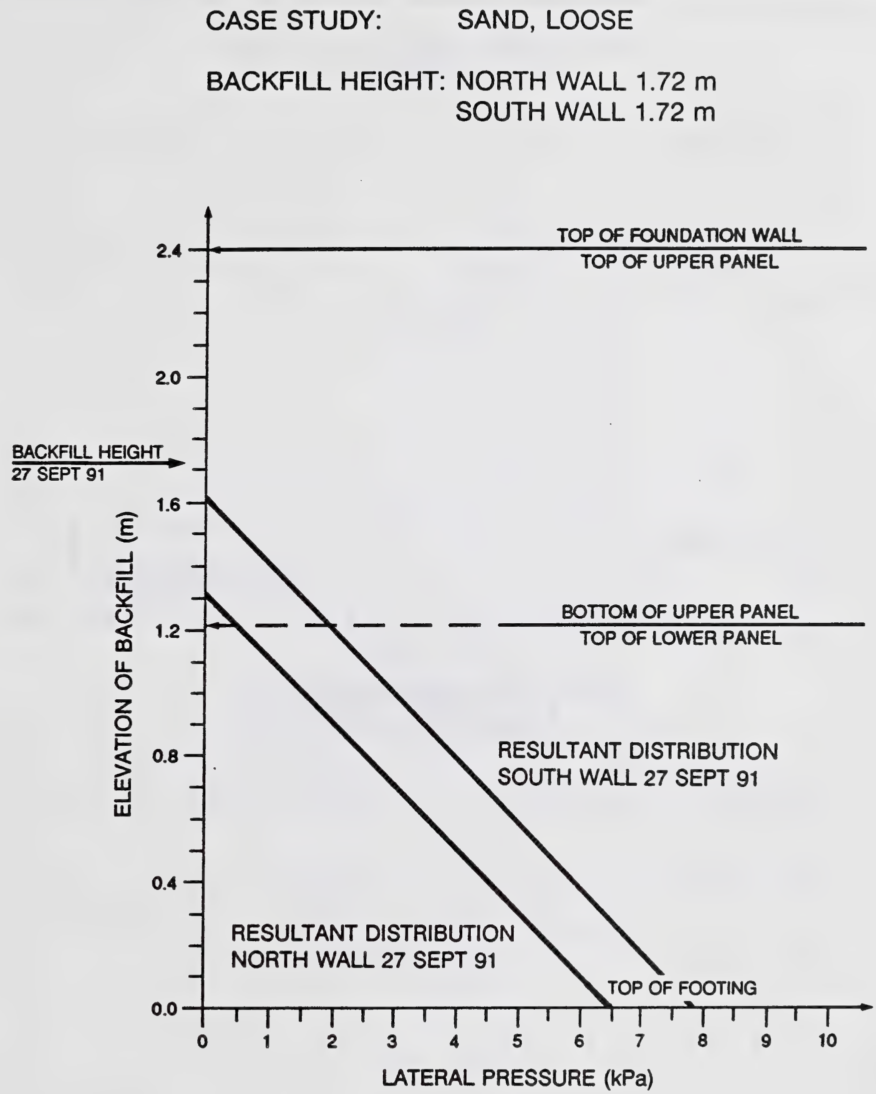
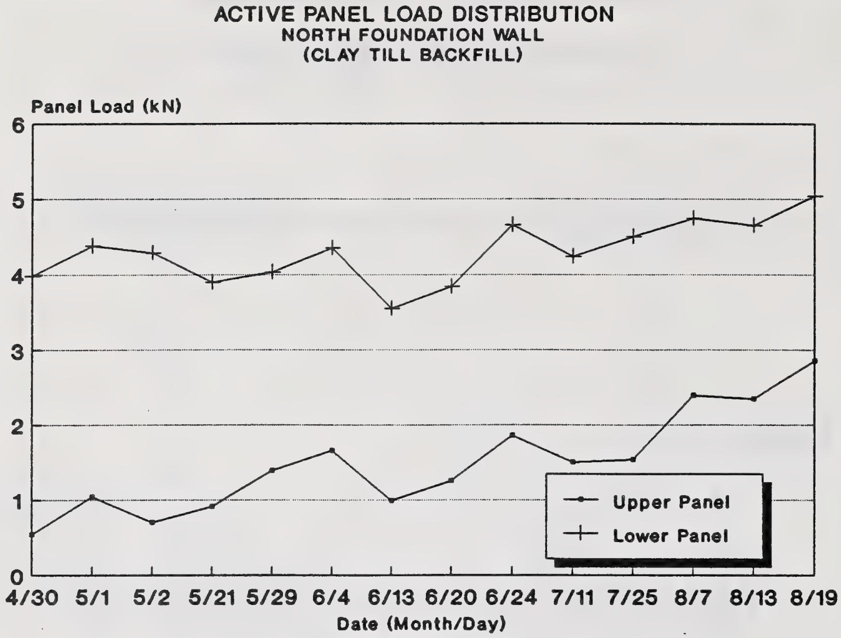


Figure 9. Lateral Pressure vs Elevation of Backfill Sand, Loose



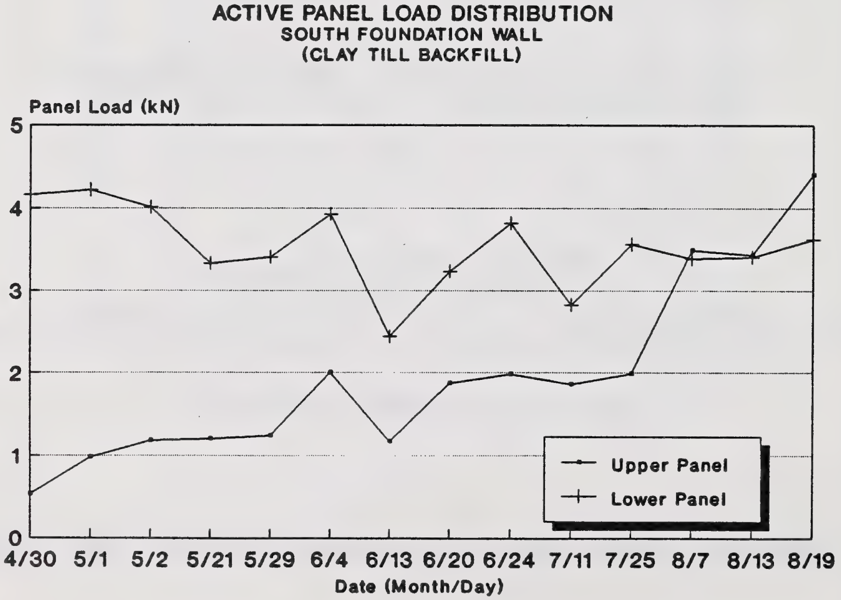


Figure 10. Panel Force Distribution: Clay Till, Tamped

APPENDIX E

SITE PHOTOGRAPHS

PHOTO 1. NORTHEAST VIEW OF EXCAVATION AND FOOTING FORMWORK.

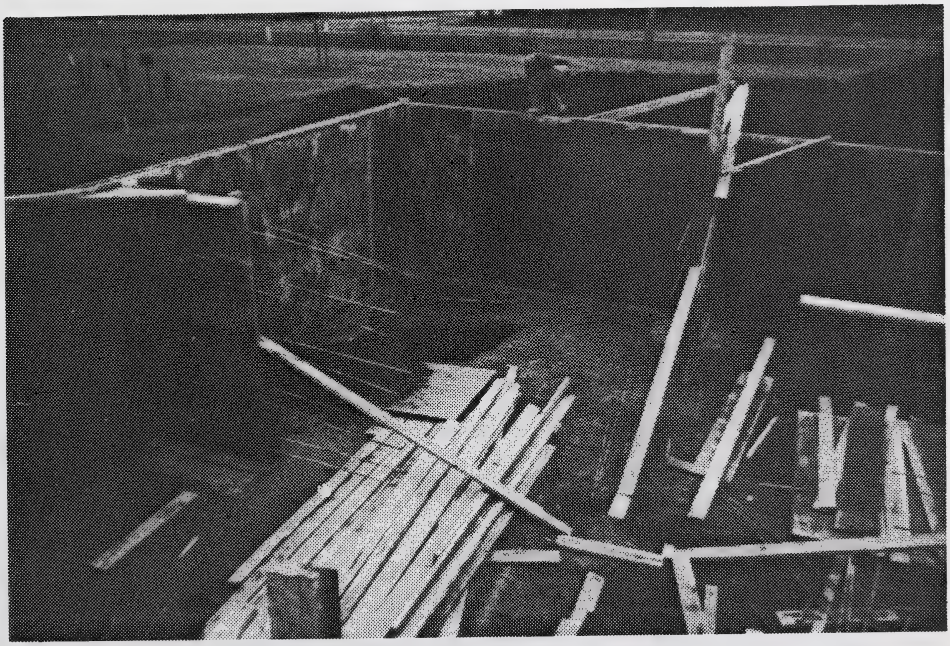


PHOTO 2. NORTHEAST VIEW OF FOUNDATION WALL FORMWORK

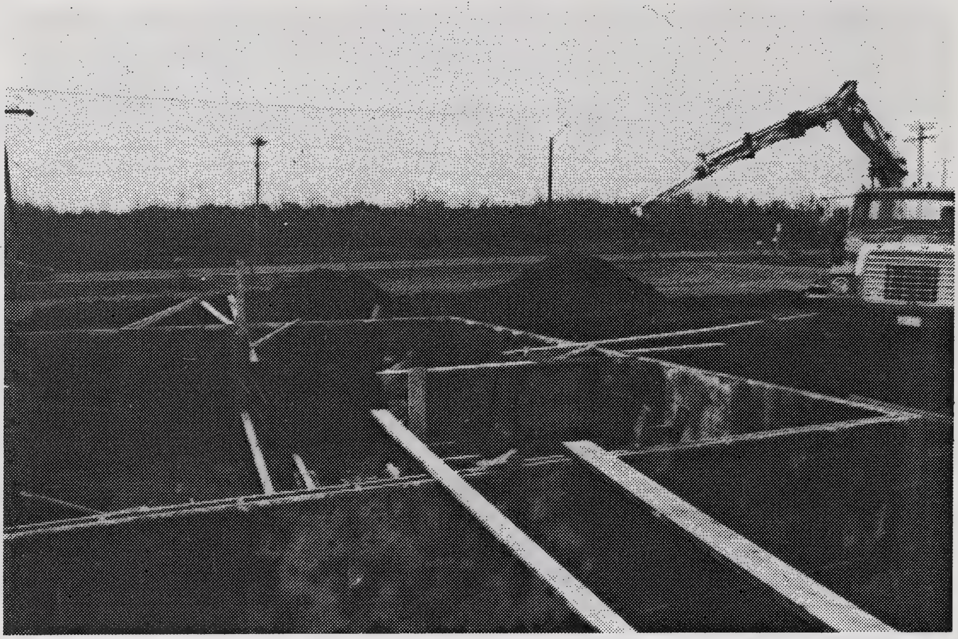


PHOTO 3. WESTWARD VIEW OF COMPLETED FOUNDATION WALL FORMWORK

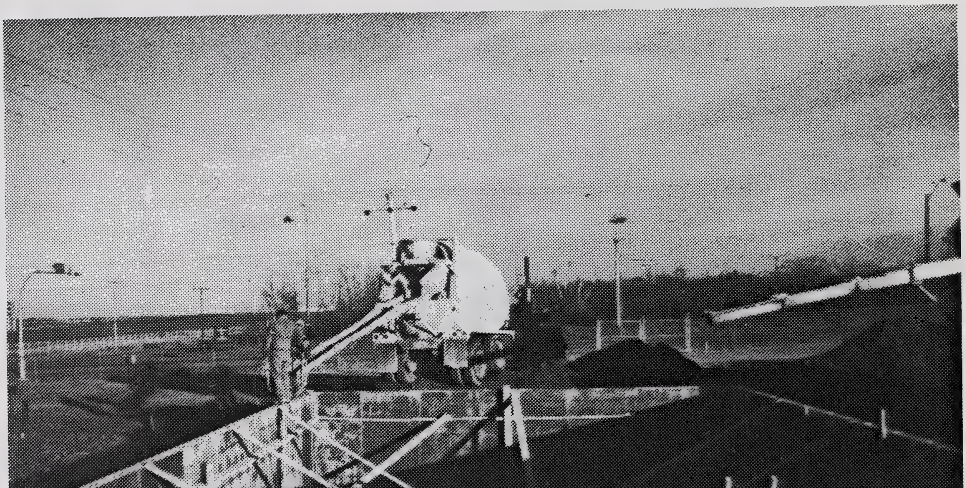


PHOTO 4. WESTWARD VIEW, POURING CONCRETE FOR FOUNDATION WALLS

PHOTO 5. INTERIOR VIEW OF NORTHSIDE SHEAR WALL

PHOTO 6. WOOD FORMS FOR REINFORCED ACTIVE CONCRETE PANELS

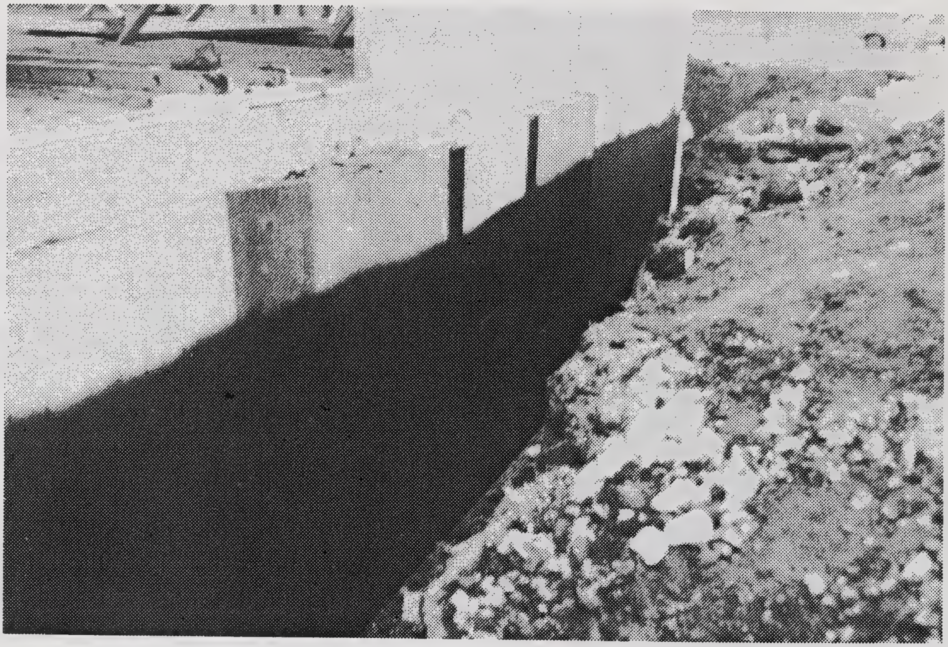


PHOTO 7. DAMPROOFED FOUNDATION WALL WITH ACTIVE/DUMMY TEST PANELS INSTALLED.

PHOTO 8. NORTHEAST VIEW OF COMPLETED STRUCTURE

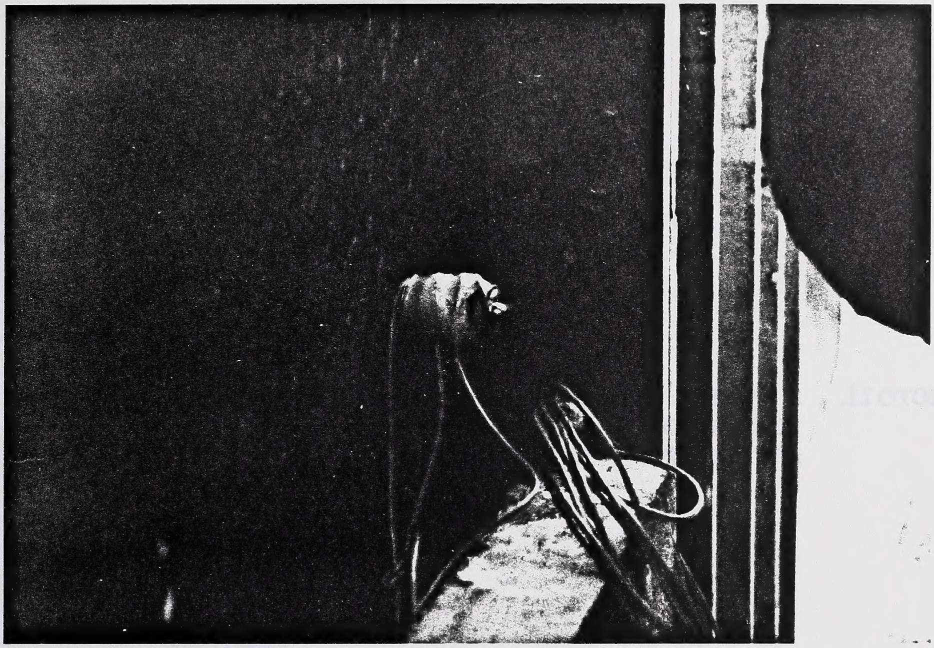


PHOTO 9. LOAD CELL MOUNTED ON FOUNDATION WALL

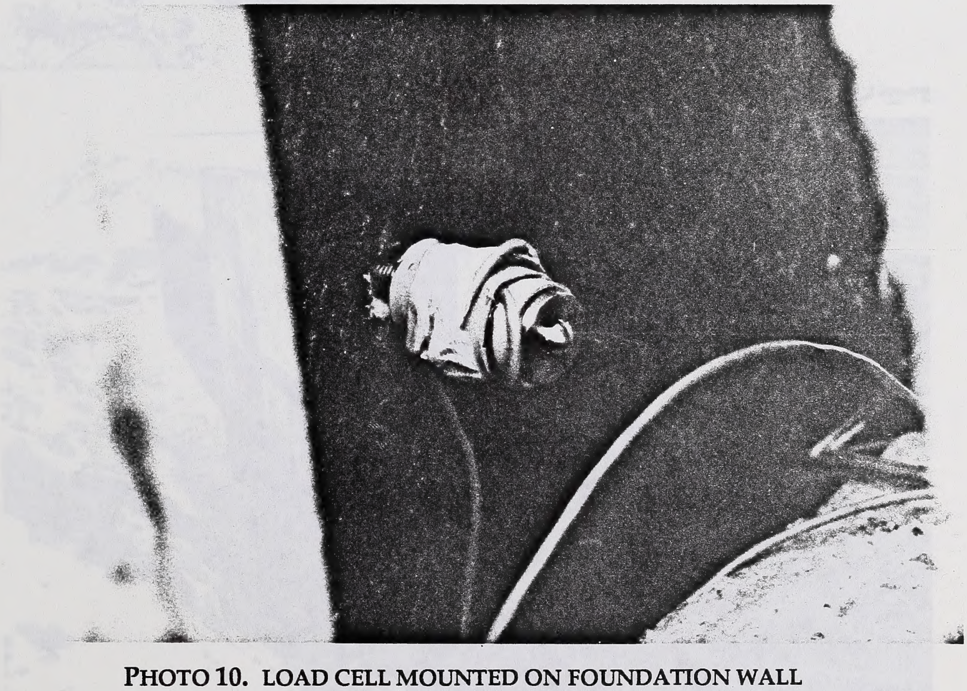


PHOTO 10. LOAD CELL MOUNTED ON FOUNDATION WALL

PHOTO 11. APPLYING BITUTHENE STRIP TO SEAL OPENING BETWEEN ACTIVE/DUMMY TEST PANELS

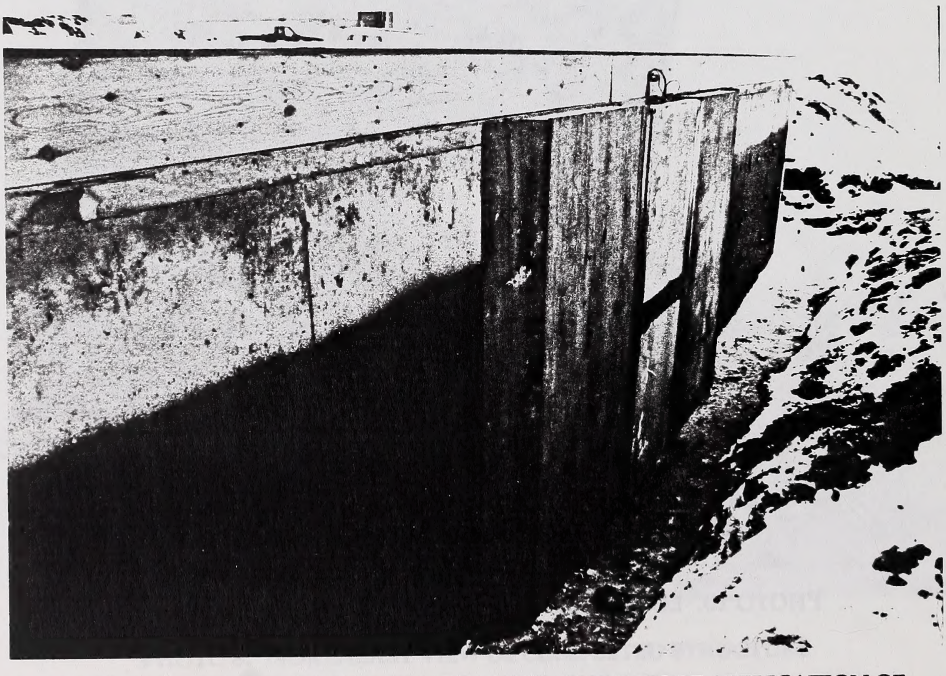


PHOTO 12 COMPLETED TEST PANEL ARRANGEMENT BEFORE APPLICATION OF DAMPPROOFING